THE VAULT OF HEAVEN

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AN INTRODUCTION TO MODERN ASTRONOMY

BY

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PREFACE

OF all branches of science, astronomy makes the widest appeal to most minds—scientific and lay—possibly because of the greatness of the conceptions with which it is concerned, but more probably on account of a spiritual instinct which turns the thoughts of man to the skies for relief from the welter and turmoil of everyday life. Interest in the wonderful cities thus seen on high is increased when something is known of them—their positions, seasonal occurrence, changes, and natures—and it is the purpose of this little book to serve as an introduction to their study.

A large part of modern astronomical achievement needs no mathematical training, or highly technical knowledge, to comprehend it; and the beauty of many pictures of celestial objects and scenery can be appreciated even when their full significance is not understood. Some of these revelations of the photography of the heavens are here reproduced by the generous permission of the astronomers and directors of observatories who secured them. Such are the marvellous photographs kindly provided by Dr. G. E. Hale, director of the Mount Wilson Observatory, Pasadena, California; by Prof. E. B. Frost, director of the Yerkes Observatory, University of Chicago; by Dr. J. S. Plaskett, director of the Dominion Astrophysical Observatory, Victoria, B.C.; by Sir Frank Dyson, Astronomer Royal; and by Mr. J. H. Reynolds, at his observatory at Harborne. If students of this book are so much impressed by these pictures as I am myself, they will understand the fullness of my gratitude to the astronomers

who have lent me such effective aid. Where the names of the actual photographers are known to me, they are given in the inscriptions of the pictures themselves.

Though this is a new edition of a book published several years ago, it has been completely revised, largely rewritten, and extensive additions have been made to it ; so that it is substantially a new volume. For most of this new matter, and for careful attention to the whole, I am indebted to Mr. D. L. Edwards, of the Norman Lockyer Observatory, Sidmouth ; and my thanks cannot here be adequately expressed to him. He will share my satisfaction if the book succeeds in its intention to combine simple instruction in astronomical facts and phenomena with stimulus to undertake their further study.

R. A. GREGORY

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THE VAULT OF HEAVEN

CHAPTER I

GEMS OF THE SKY

A VIEW of the sky on a fine night "when all the stars shine, and the immeasurable heavens break open to their highest," excites the wonder and stimulates the imagination of every thoughtful mind. Like brilliant gems set in the roof of a vast dome, the heavenly bodies glitter and gleam upon the dark background of space, making us conscious of the immensity of the universe in which the earth plays so insignificant a part.

The glories of the heavens have appealed to all people at all times. To primitive men, the earth appeared to be the centre of the universe, and all the heavenly bodies were supposed to be subservient to it. In that remote day, when science was reduced to simple deductions from the obvious, it was concluded that all things were made for man's especial benefit, the sun to serve him by day and the moon by night. The movements of the heavenly bodies were then observed because of their relation to the seasons; and from the idea that these motions were created for the convenience of mankind alone, grew the pseudo-science Astrology.

But clocks and calendars render it no longer necessary to note the position of the sun in order to tell the time of day, or to determine the month by observations of the stars visible in the midnight sky. The observational

astronomy of the ancients, dealing with the positions and apparent motions of the heavenly bodies, is, therefore, no longer a common possession, and its votaries are usually confined to astronomical observatories. The feeling of wonder at the profundity of space, and of admiration at the beauties of celestial scenery, is felt by all; but while in some minds the wonder is barren, in others it gives rise to profitable thought.

An inquiring glance at the night sky will show that many of the bright stars form well-marked groups, which have the same configuration night after night. Nearly eighteen hundred years ago, Ptolemy divided the stars into forty-eight groups or constellations, to each of which was given the name of a character in Greek mythology. The curious figures which appear upon star-maps and celestial globes represent Ptolemy's constellations, with the addition of about twenty more created by later astronomers. In many modern star-maps the old figures are omitted, though the distinctive names are retained. The limiting lines of the groups serve as convenient boundary marks, and are used in much the same way as the divisions which separate the earth's surface into countries.

To the geographical mind, the names of countries, such as France or Italy, convey a definite idea of situation on the earth's surface. In like manner, the astronomer is generally so familiar with the face of the sky, that, when he observes any celestial phenomenon, he is able to say whether it occurred in Orion, or Cassiopeia, or the Plough, or any other constellation. The terrestrial analogy can be carried still further. Bright stars are dotted over the sky like towns on the earth. Many of them possess proper names, such as Sirius, Vega, and Arcturus, but generally the letters of the Greek alphabet are used to designate the stars in a constellation, the brightest star usually being called Alpha, the next brightest Beta, and so on through the whole of the alphabet. A star may, therefore, have several aliases. Thus, Sirius is Alpha of the Great Dog

constellation (usually written α Canis Majoris), Vega is Alpha of the Lyre (α Lyræ), and Arcturus is α Bootis.

The stars appear to move from east to west as if they were fixed to a solid revolving vault. This motion is not real, but merely an apparent motion caused by the rotation

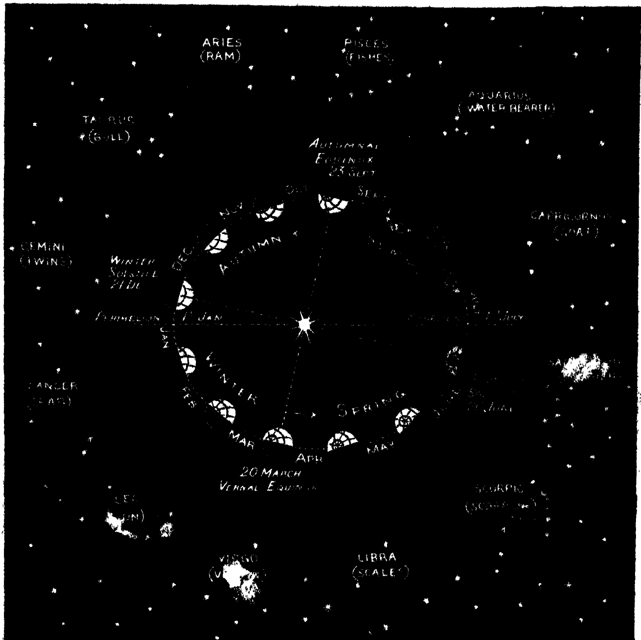


FIG. 1.—The Signs of the Zodiac in relation to the Earth's annual revolution around the Sun. In the course of a year the Sun is projected in succession upon each of the twelve constellations of the zodiac.

of the earth from west to east on its axis. The daily travel of the sun across the sky is explained in the same way. It is day when the place on the earth occupied by us is turned towards the part of space occupied by the sun, and night when we are turned away from its beams. The sun

also appears week by week to move upwards from the western horizon towards the stars, those high above the western horizon at sunset at any time of year being, a few weeks later, lost in the glows of twilight; and, shortly after, setting at the same time as the sun. In a year, however, the same stars are found to occupy the same relative position as regards the setting sun that they did previously.

The groups of stars through which the sun thus seems to pass in the course of a year is called the "Zodiac." This apparent eastward motion of the sun among the stars is the result of the earth's annual revolution around the sun; and the path traversed is known as the "ecliptic." The earth is, indeed, a moving observatory; and the stellar background upon which the sun is projected differs according to the position of the earth in its orbit. Stars behind the sun at midday to-day, will be due south at midnight in six months' time; while those now visible at midnight will form the midday background. In the day, sunlight illuminates the atmosphere to such an extent that the feeble star-beams are overpowered. Could the sun be annihilated at any moment, or the earth stripped of its atmosphere, the stars would be seen brilliantly shining on high.

No telescope is necessary in order to become acquainted with the chief constellations, the bright stars in them, the chief planets, and the apparent movements among the stars of objects belonging to the sun's system. The following brief description of the stars visible at different seasons of the year from the northern hemisphere of our globe will serve as guidance to some interesting aspects of the sky at night.

The Northern Constellations.—The stars of the northern sky are unique in the fact that they are visible on fine nights in the northern hemisphere all the year round. The rotation of the earth on its axis merely causes the stars apparently to travel in circles

around the "North Celestial Pole," which is that point on the celestial sphere corresponding to the North Pole of our earth. These stars are therefore called circum-

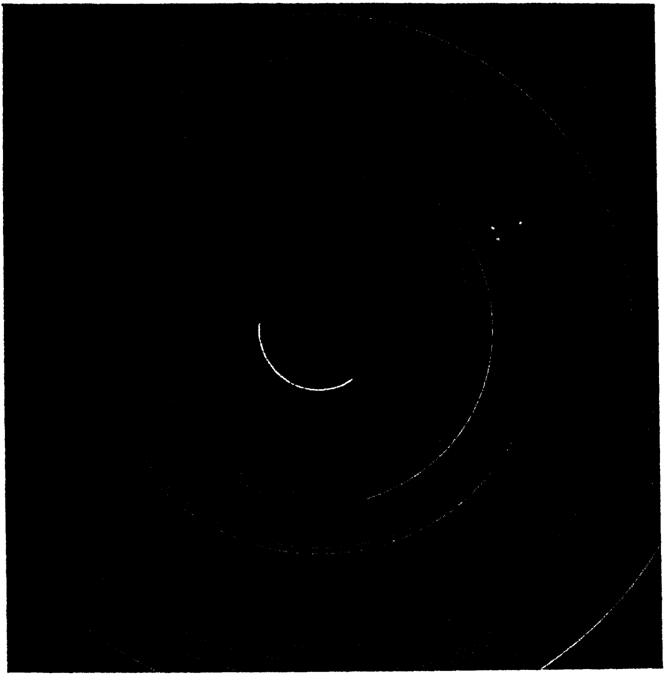


FIG. 2.—Photograph of star trails around the North Celestial Pole. The bright arc below the centre is the trail of the North Star, which is thus seen to be not actually at the Pole.

polar, and although always visible, they are seen in different positions, according to the time of year.

The principal constellation visible in this region of the sky is that known as the Great Bear, or the Plough (Fig 3) This is probably the best known of all constellations, and forms a useful starting point from which to pass to

others. The two stars farthest from the handle of the Plough are called "the Pointers," from the fact that they point in the direction of an important star which marks, very nearly, the position of the north Celestial Pole. This is known as the Pole Star or North Star, and it belongs to

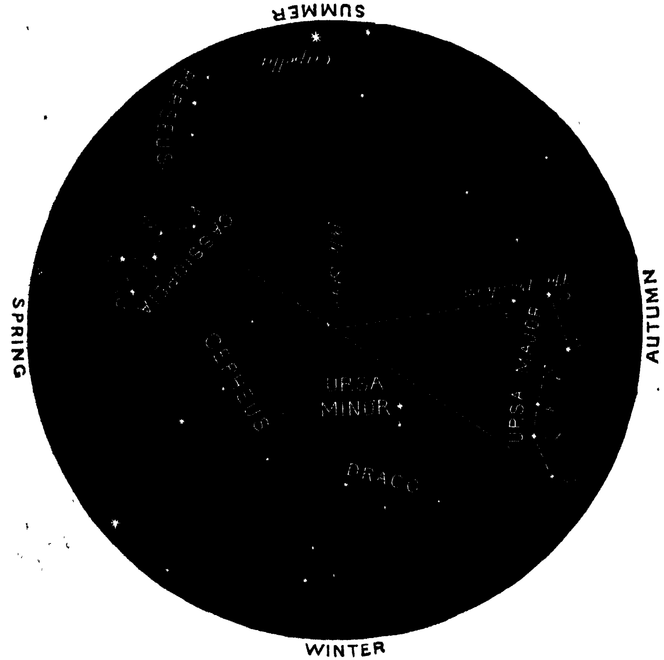


Fig. 3.—Stars seen when looking north on any fine night in the northern hemisphere. The figure should be turned so that the season is at the bottom; the stars will then be in the positions shown about 10 p.m.

the constellation of the Little Bear—a group of stars similar in arrangement to the Great Bear, and of which the Pole Star forms the end of the tail.

A line drawn from the tail of the Great Bear to the Pole Star, and produced to the same distance on the other side

of the latter, indicates another striking group of stars known as Cassiopeia. The brighter stars of this constella-

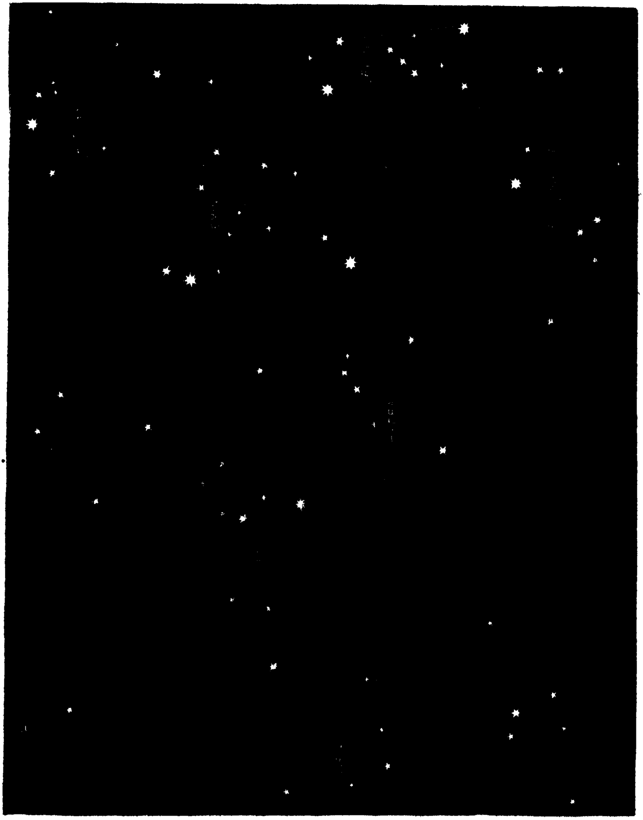


FIG. 4.—Stars visible in spring in the northern hemisphere.

tion form a very distinct W and are easily recognizable (Fig. 3).

The Night Sky in Spring.—The chief constellation visible in the southern sky during a spring night is that

named Leo, from its very fair resemblance to a recumbent lion (Fig. 4). Leo may best be picked up by following

FIG. 5.—Stars visible in summer in the northern hemisphere.

the line of the Pointers in a direction away from the Pole Star, when the eye will at once be led to the body of the lion. The brightest stars in this constellation are Regulus, near the front paws of the lion, and Denebola in its tail.

To the east of Leo will be seen the constellation Bootes, of which the principal star, Arcturus, is one of the brightest stars visible from this hemisphere (Fig. 5). By following

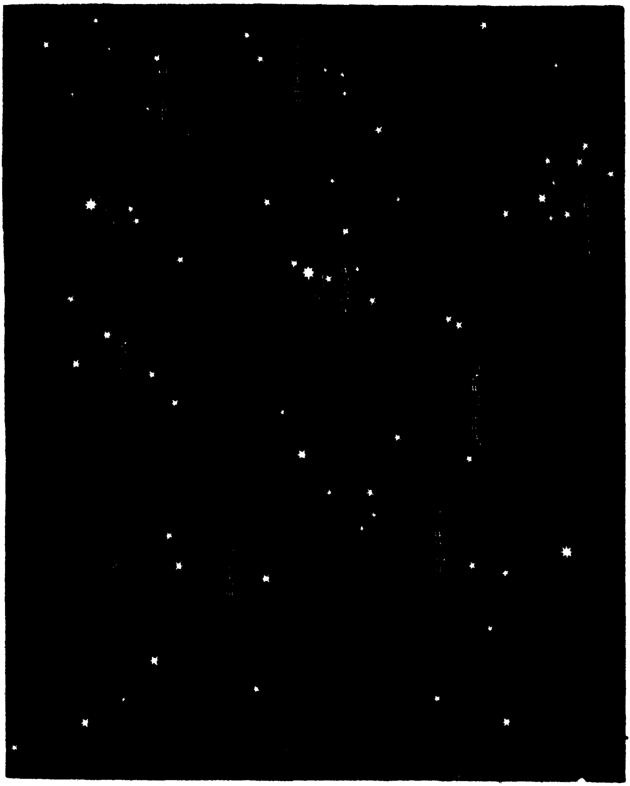


FIG. 6.—Stars visible in autumn in the northern hemisphere.

the line from Regulus to Denebola onwards for rather more than its own length, Arcturus will easily be found. To the west of Leo, a pair of fairly bright stars may be noticed lying in the direction of a line from Denebola through the

head of the lion. These stars are named Castor and Pollux, and are the brightest stars in the constellation Gemini (the Twins).

The Night Sky in Summer.—The gem of the summer nights is undoubtedly the brilliant star Vega, or Alpha Lyræ, which almost equals Arcturus in brightness and is of a much less ruddy tint (Fig. 6). It can be seen very high up, almost overhead at midnight, and is easily distinguished by its brilliancy.

Between Arcturus and Vega, and rather nearer to the former, is a pretty little group of fainter stars arranged in the form of a semicircle. This is Corona Borealis (the Northern Crown). Slightly nearer to Vega lies the larger constellation of Hercules, which does not, however, possess any very well-marked features (Fig. 6). A little to the east of Vega is a very prominent group forming a well-defined cross, known as Cygnus (the Swan), and to the south of this will be found three stars in a line, the middle one being quite bright. These are in the constellation Aquila (the Eagle) the bright star being Altair (Fig. 6).

The Night Sky in Autumn.—When looking south during the autumn nights one can scarcely avoid noticing the Great Square of Pegasus. This is a conspicuous group of four stars which form the corners of a large square (Figs. 6 and 7). The continuation of a line from Vega through the centre of the cross of Cygnus will serve to point out this group if any such aid be required. Three of the stars in this figure belong to the constellation of Pegasus, but the fourth (that in the north-east corner) is the brightest star in Andromeda. It is worth while remarking that this star marks very nearly the position of an imaginary celestial line of great importance. It may be defined roughly as the line joining this star to the Pole Star, and corresponds to the Greenwich meridian on our earth. Just as the position of a place on the earth may be indicated by latitude and longitude, so a star may be located by

similar co-ordinates in the sky. These are called "Right Ascension" and "Declination," and are described more fully in the next chapter (p. 21). The line mentioned

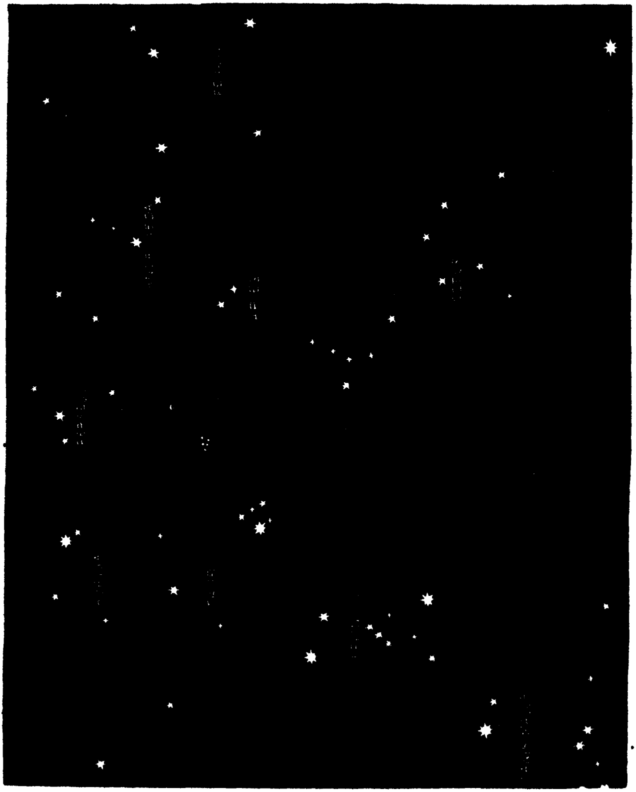


Fig. 7.—Stars visible in winter in the northern hemisphere.

above is the zero line from which Right Ascension is measured.

The Night Sky in Winter.—In the eastern sky during the winter nights will be seen the constellation of Leo

rising with the promise of returning spring, while the departure of autumn is signified by the presence of Andromeda and Pegasus low down in the north-east. The great beauty of the winter sky is, however, to be found in the splendid group named Orion, which is decidedly the finest in the sky (Fig. 7). When looking towards the south, one can scarcely fail to be attracted by the sight of this constellation, which contains a row of three bright stars (forming the "Belt of Orion") and two very brilliant stars, one above and one below this belt.

Two other fairly bright stars placed as in Fig. 7 indicate respectively one hand and a foot of Orion.

If the line of Orion's belt be produced downwards it will lead to the star Sirius, which is the brightest star to be seen in the whole sky. It is the principal star in the constellation of Canis Major (the Great Dog). The same line continued in the opposite direction will lead to the bright star Aldebaran, which is decidedly red in colour. A little farther in the same direction is a beautiful little group of stars called the Pleiades, closely clustered together. Aldebaran and the Pleiades both belong to the constellation Taurus (the Bull). Between Orion and Leo will be seen the constellation Gemini already mentioned, and below this is Canis Minor (the Little Dog), the brightest star of which is Procyon (Fig. 4).

Above Orion, and roughly midway between his belt and the Pole Star, is Capella, in the constellation Auriga.

Scattered at intervals among the stars are objects known as nebulæ. These, as their name implies, have the appearance of cloudy and more or less irregular patches of luminosity. They are found to be actually immense "clouds" of various gases, rendered incandescent through the effect of heat, which is possibly assisted by electrical action. The nebulæ are usually very faint, though a few are bright enough to be visible to the unaided eye. Among the brighter nebulæ may be mentioned the great nebula in Orion (situated in his sword handle) and that in Andro-

meda. There are also "Star Clusters," which are groups containing large numbers of stars so closely clustered together that the appearance of the whole sometimes closely resembles that of a nebula. The term "cluster" is rather broad in meaning, and is used to include groups from such as the Pleiades (mentioned above) down to those in which the most powerful telescope is required to enable their individual stars to be distinguished.

Though the stars preserve practically the same relative positions upon the celestial vault from year to year, other bright, star-like objects can frequently be seen which change their places among them. These are not stars at all, but planets or wanderers, revolving round the sun in orbits similar to that traversed by the earth. There are seven large planets in addition to the earth, and about one thousand small ones, known to be under the controlling influence of the sun. Around the earth and five other planets revolve one or more moons, but with the exception of our own satellite, none of these planetary attendants is visible to the naked eye.

Among the remaining celestial objects which are dealt with in this book, are the comets and shooting stars. Comets, like planets, do not remain fixed in position relatively to the stars, but move continuously among them. Their wanderings are, however, more erratic than those of the planets, since in many cases a bright comet makes one journey only round the sun and then departs, perhaps never to return again.

CHAPTER II

OBSERVATIONAL AIDS

BY looking through two spectacle glasses held a short distance apart, objects can be made to appear nearer. The story goes that a child's exclamation of wonder at the appearance of a church spire seen under such conditions attracted the attention of one, Jean Lippershey, an optician of Middleburg, in Holland, about 1606, who afterwards fixed the lenses in tubes to form the first telescope. A patent was applied for but refused, on the quaint ground that the instrument only used one eye, whereas Nature had endowed us with two.

Galileo heard of the discovery in 1609, and made a telescope on the same principle. The instrument had lenses similar to those in a common opera-glass and magnified only thirty times. However, such optical aid enabled Galileo to discover spots on the sun, to see four moons revolving round Jupiter, to view the phases of Venus, observe mountains in the moon, and distinguish a large number of stars invisible to the naked eye. A new kind of astronomy was thus founded. Before the invention of the telescope the positions and motions of the heavenly bodies were the subject of study; after, it became possible to inquire what the objects are in themselves.

Though a modern astronomical telescope, with its numerous and complicated accessories, differs very considerably in appearance from the simple instrument used by Galileo, the optical principles underlying the construction of the two are much the same. Both consist essentially of a large lens, termed the "objective" or

"object-glass," to form an image of the object under examination, and a small lens, or combination of lenses, to magnify the image. If the functions of these glasses are properly understood, the power of a telescope to reveal faint objects, and to magnify them, can always be estimated.

With a lens ten inches in diameter, two thousand five hundred times more light is caught than with the pupil of the unaided eye, which is only about one-fifth of an inch in diameter. The luminous image formed by such an object-glass is not, however, increased in brightness by this proportion, on account of the absorption of light by the lenses.

The part played by the object-glass is to increase the apparent brightness of objects by collecting the light from them and bringing it to a focus. On account of the light-collecting property of an object-glass it is possible to see the brighter stars in the day-time with a telescope of moderate dimensions. The few rays of light that enter the pupil of the eye from such stars are insufficient to produce the sensation of sight, whereas the larger bundle of rays, collected by the lens and concentrated into a beam small enough to enter the pupil, is sufficient to do so. For the same reason, a telescope is able to reveal stars quite beyond the reach of the unaided eye. The larger the object-glass, the larger is the bundle of rays collected by it, and the greater is the ability of the instrument to bring faint objects into view.

The power of a telescope to magnify the heavenly bodies is obtained by means of the lens, or combination of lenses, at the eye end. Usually several "eye-pieces" are supplied with a telescope, and a large instrument has a stock capable of magnifying from fifty to about one thousand times.

Let us consider exactly what this means. A man at a distance of a thousand yards appears to have a certain height. If a telescope, with a magnifying power of two, is used to view the individual, he will appear as if seen at

half the distance ; a magnifying power of three will enable us to see him as if he were situated at one-third the distance,

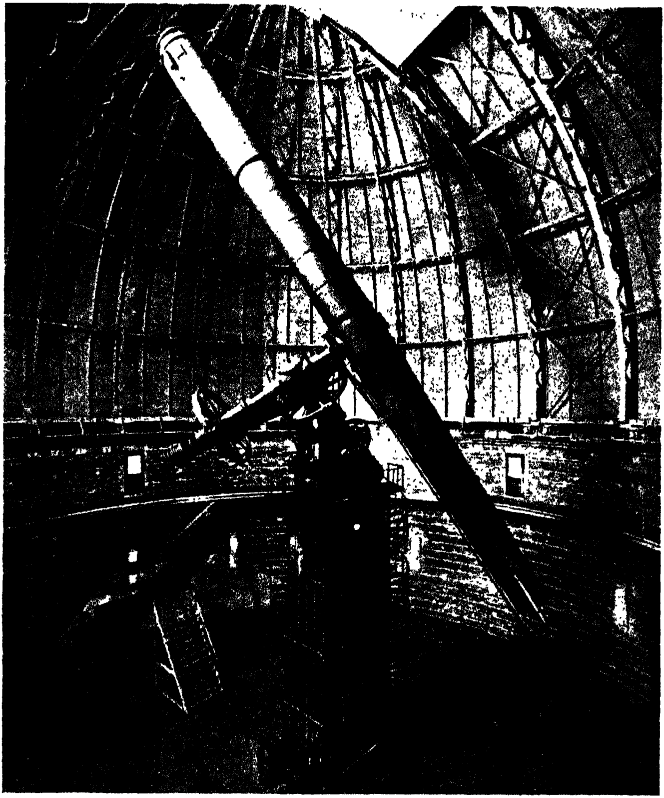


Fig. 8.—The great telescope of the Yerkes Observatory, University of Chicago. The object-glass has a diameter of 40 inches.

and so on for other magnifications. When the man is seen at half his original distance, his apparent height is doubled. In the same way magnifications of one, two, three, or four hundred bring the selected object apparently

one, two, three, or four hundred times nearer, and the size of the object is increased according to the proportion which the diminished distance bears to the real distance. This principle applies to celestial as well as terrestrial objects. The moon is at a distance of 240,000 miles from the earth. If this distance could be halved, the apparent diameter of the moon would be doubled. We cannot, of course, increase or decrease the real distance of the moon, but by magnifying our satellite we can bring about the same result so far as appearances go. An instrument of moderate dimensions will show the moon as it would be seen at a distance of five hundred miles, and any lunar streak or mark a quarter of a mile in width can then be easily distinguished.

There is a limit beyond which magnification cannot be carried with advantage, due to the fact that we see things through an atmospheric veil. When objects such as the sun, moon, or planets, are magnified telescopically, the tremors of our aerial envelope are magnified in the same proportion. Hence a condition is eventually reached when atmospheric imperfections become so troublesome that further improvement of seeing is rendered impossible. For many observations in astronomy, however, a high magnifying power is undesirable and in some cases useless. The stars are so far away from us that they cannot be magnified by the use of any telescope. In a good instrument, a star appears simply as a point of light more or less brilliant according to the size of the object-glass, but possessing no particular features. Indeed, the existence of a pretty colour round the image of a star is an indication that the telescope is not so perfect as it ought to be. But though stars cannot be magnified, the space between them can. Hence it is that many stars which appear single when viewed in a small telescope are found to be composed of two when seen with a high magnifying power on a telescope.

A large telescope is of very little use unless it is mounted

so that it can readily be pointed towards any part of the sky. More than this, on account of the apparent motion of the celestial sphere, if a telescope is sighted at a star, a

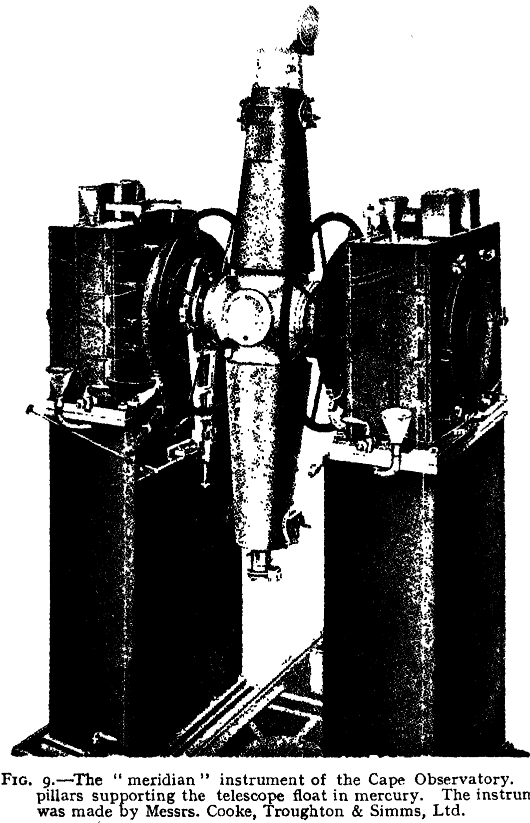


FIG. 9.—The "meridian" instrument of the Cape Observatory. The pillars supporting the telescope float in mercury. The instrument was made by Messrs. Cooke, Troughton & Simms, Ltd.

few minutes afterwards the star has been carried towards the west, and the instrument is left pointing to another object. If we wish to observe the star continuously, the telescope must be moved at the same rate as the apparent

motion of the sky. These conditions have to be realized in all telescopes designed for the study of celestial objects. An astronomer first points his telescope to the object he wishes to observe, and then connects it with a clock-work arrangement, which will drive it at the same rate as the stars. Should the sky afterwards cloud over, the telescope can be left to itself for a time, but when the sky is clear again the astronomer goes back, and is able to continue his work with little or no readjustment, for the instrument will still point to the object to which it had been directed.

In addition to the instruments used for observing the physical characteristics of celestial bodies, there is a class the function of which is to determine positions accurately. The former is for celestial sight-seeing, the latter furnishes the facts for mathematical investigations. This kind of instrument is not mounted so that it can be directed to any part of the sky. Crossing the middle of the tube is an axis, which rests on two firm supports, and points exactly due east and west. The tube itself thus always lies in a true north and south direction. It can be moved up and down, but neither to one side nor the other. Upon looking through a "meridian instrument" of this kind, several very fine upright lines will be seen, with one or two others crossing them horizontally. These lines—usually made of spider thread—serve a most important purpose. The instrument is fixed. In stately and grand procession the stars appear at one side, cross the upright lines one after the other, and then disappear on the opposite side.

If the exact time at which a star crosses the central upright line is noted two nights in succession, the interval will be found to be 23 hours, 56 minutes, 4 seconds of mean time. Whatever star is selected and whenever the observation is made the interval is always the same; it is the time taken by the earth to rotate on her axis, and is known as a sidereal or star-day. For astronomical purposes the star-day is used instead of the day of civil life. The astronomical clock has the same appearance as a well-constructed clock

keeping ordinary time ; indeed, if it were required, it could be regulated to keep ordinary time. Astronomers want the clock to keep star-time, so it is regulated until the hour hand goes through the twenty-four hours marked on the face in the interval between two successive passages

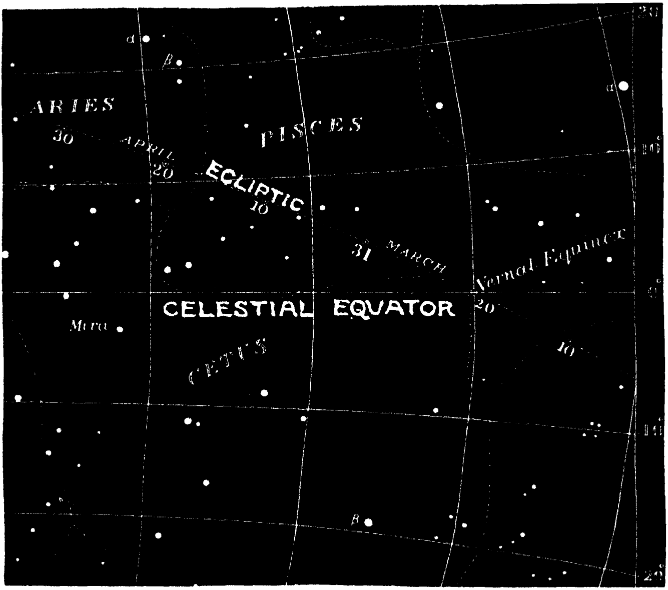


FIG. 10.—Intersection of the ecliptic and the celestial equator, showing the "First Point of Aries," at the vernal equinox, now in the constellation Pisces.

of a star across the central line of the meridian instrument. When this is the case, the hour hand makes a complete revolution in 23 hours, 56 minutes, 4 seconds, of ordinary time. An astronomical clock, therefore, gains about four minutes a day upon the time in general use.

It is so arranged that the clock of the astronomers always indicates 0 hours, 0 minutes, 0 seconds, when a particular point in the sky is due south, that is, on the

meridian. The point selected is that upon which the centre of the sun is projected at the time of the spring equinox (March 21), and its position in the sky is very accurately known. Once a day it passes across the field of view, and when it does so, the clock begins its round of twenty-four star-hours. A simple means of determining the approximate position of this point, relatively to the meridian, by an inspection of the stars has been described on p. 10. Suppose the star-time to be 3 hours, 6 minutes, 18 seconds, when a certain star is observed to transit; then whenever the sidereal clock indicated that time at the place, whether by day or night, the star would be in the same position, presuming, of course, that the clock was an absolutely accurate timekeeper. In other words, the sidereal time indicated when any star transits a particular meridian is always the same for the same star. This furnishes a means of determining the positions of stars round the sky in an east and west direction. The number of sidereal hours, minutes, and seconds which elapses between the passage of the starting point and the passage of a star across the centre of a meridian instrument is observed, and termed the star's "Right Ascension."

Evidently, many stars have the same right ascension, that is, they are due south at the same time, though at different heights above the horizon. Hence, to locate a star exactly, we must not only know the distance in an east and west direction from a "prime meridian," but also north and south of a fixed datum line. Suppose we could see twenty-four lines, each stretching from the north to the south celestial pole, like the lines of longitude upon a map or globe of the earth; the interval between two lines would then represent an hour of right ascension. Now, the celestial poles are the points in the sky around which the stars appear to revolve, and the celestial equator is midway between them. If the two legs of a pair of compasses are opened until they are perpendicular to one another, and one of them is pointed towards a celestial

pole, the other then points to the celestial equator. The smallest angle between the legs when one points to the equator and the other to a star, in other words, the angular distance of a star from the celestial equator, goes by the name of "Declination." It corresponds to terrestrial latitude. Every one knows that the position of a place upon the earth is defined when its latitude and longitude have been obtained. In a similar manner every star in the sky has a particular Declination and Right Ascension, and when these two co-ordinates are known the star can be found.

In modern astronomical observatories the photographic plate has very largely taken the place of the human eye; and the advantages of photography over visual observations are many. To begin with, the human eye, considered as an optical instrument, is full of imperfections. It is extremely rare to find the two eyes of a person exactly alike, or to find two people with exactly the same power of seeing. Nowhere is this fact more clearly manifested than in the records of observational astronomy. Fortunately, the photographic plate is unable to exercise the faculty of imagination. It infallibly records the impression received. If the lens of the camera or the telescope is imperfect, the image of an object is also imperfect, and the photographic picture obtained testifies to the fact.

Another advantage of the photographic plate over the human retina is that its range of sensibility is greater. We cannot perceive luminous vibrations more rapid than those which produce the impression of violet light, or slower than those which give us the sensation of deep red light, whereas an ordinary photographic film is sensitive to vibrations within our range, and also to others far beyond it which are utterly powerless to produce any visual effect. Further, a peculiar advantage of the photographic plate is its ability to accumulate impressions. The human eye soon tires, the best view of an object being

generally obtained at first sight. With a sensitive film, the reverse is the case. The light of an object may be so faint as to be unable to be grasped by any observer with any telescope. It may not leave any mark upon the photographic plate after beating upon the sensitive surface for several minutes, but let the action continue for a longer time, and that which was invisible will be revealed. Apparently blank spaces in the sky have thus been shown to be filled with stars and faint nebulosities previously unknown to exist.

The modern astronomical telescope has a number of other accessories, but it would be out of place to describe them here. Our knowledge has been extended in unhoped-for directions by means of the photographic camera and the spectroscope, and some of the results obtained with these potent engines of research will be described in later chapters.

CHAPTER III

THE LANTERN OF THE WORLD

IT is the sun that guides the planets in their course and renders the earth an habitable globe. This orb of heaven is so majestic in his motions, so mighty in its terrestrial influence, that many primitive peoples have made it an object of worship. To the Egyptians the sun was a god, and they built temples to point to its position at rising or setting at particular times of the year; both as an act of reverence, and for the practical purpose of marking out seasons. Here we shall regard the sun as a globe to be measured and analysed, and state some of the main characteristics determined by modern inquiry.

The distance of the sun from the earth is about 93 millions of miles. There is a difficulty in properly grasping the significance of this immense number. If we could stretch a row of bodies of the same size as the earth across the abyss which separates us from our luminary, the number required to complete the line would be 11,600. Nowadays, a number of people travel completely round this world of ours. Roughly speaking, "the grand tour" involves a circuit of about 24,000 miles, and may be done in about sixty days. In order to travel as many miles as separate us from the sun it would be necessary to make nearly four thousand such journeys, and if a traveller started on his circuits as soon as he was born, he would require to live about 650 years to finish his task. Let us take another illustration. A sensation travels through the nerves at the rate of about a hundred feet in a second. Imagine a man could stretch out his arm and reach to the

sun so as to burn his finger; the sensation would start on its journey, but 160 years would elapse before it had reached his brain and made him realize the pain. Sound travels through the air at the rate of about 1,100 feet per second. If it could be transmitted through space with the same velocity, an explosion on the sun would be heard on the earth rather more than 14 years after it had occurred Light is a much swifter messenger. It travels at the enormous rate of 186,000 miles in a second, so that the light we receive from the sun at any instant left it eight minutes previously.

The sun is three million miles nearer the earth in winter than in summer. The difference between the greatest and least distances is found by measuring the change in the sun's apparent size. The annual variation amounts to one-thirtieth of the whole solar diameter. Now, there is a very definite relation between apparent size and distance. A stick a yard long seen at a distance of 50 yards appears of the same size as one two yards in length at twice the distance, or three times the length at three times the distance. In fact, if two objects at different distances appear of the same size, the real sizes are exactly in proportion to the distances. Let us apply this principle to find the size of the sun. A halfpenny placed at a distance of nine feet from the eye just covers up the sun's disc. The diameter of the coin is an inch. Hence an inch at nine feet appears of the same size as the sun, which is 93 million miles away. The sun has therefore a diameter as much longer than that of the halfpenny as 93 million miles exceeds nine feet. By working out this proportion the diameter is found to be about 860,000 miles. Accurate measurements show that the value is 866,000 miles. Comparing this with our own globe, we find that it would take 109 earths in a row to stretch from one side of the sun to the other, and 342 would be required to make him a girdle. The sun's volume is more than one and a quarter millions greater than that of the earth. If a superman had a contract to

build up this stupendous bulk, and were to deliver a load of the same size as the earth every hour, the order could be completed by working day and night for 150 years.

Though the sun is 1,300,000 times bigger in bulk than the earth, it is not the same number of times heavier. It weighs 330,000 times more than the earth, and its density, that is, heaviness, bulk for bulk, is about one quarter that of the earth. The earth, as a whole, is rather more than five and a half times heavier than a globe of water of the same size; the sun, as a whole, is less than one and a half times heavier than it would be if composed of water. But we hasten to remark that the density of both the sun and the earth increases from the surface down to the centre. The upper parts are lighter, bulk for bulk, than the lower, and the numbers given represent the average density.

The weight of a body on the earth is simply the pull of the earth upon it. At the sun's surface, the pull is nearly 28 times greater than at the surface of our globe. It results from this, that anything transported to the sun would appear to have its weight increased nearly 28 times.

To the naked eye the sun appears like a flat disc, but when observed with even a small telescope many interesting structures can be seen. In making such observations, however, some method of screening the eye from the fierce beams of the sun must be used. A tinted glass is usually put over the eye end of the telescope, and in a small instrument this tones down the light and heat sufficiently to permit the solar surface to be observed. For large instruments, special devices are employed to diminish the power of the rays before they reach the eye-piece and dark glass; if this is not done, the great heat may melt the tinted glass, besides injuring the eye of the observer. Another method of viewing the sun's surface is to fix or hold a sheet of white cardboard at a short distance from the eye-piece. The sun's image will then be projected upon the card, and

any spots or markings upon the surface are conveniently seen.

One of the first things that strikes a solar observer is that the visible surface of the sun—the "photosphere,"

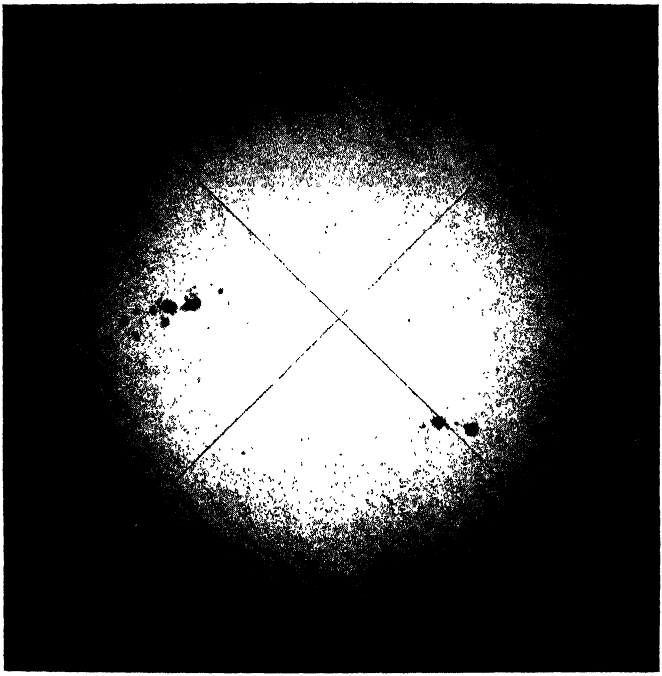


FIG. 11.—Photograph of the sun and sun-spots taken at the Royal Observatory, Greenwich, on January 25, 1920.

to give it its name—is darker near the edges than at the centre. A close investigation of the photosphere shows that it has a texture, a mottled appearance, very similar to that of mottled cardboard. The marks go by the name of "nodules" or "rice-grains," and though they are "minute" objects on the sun, the smallest are as large as

Great Britain. In places the rice-grains are seen to be lengthened so as to have the form of "willow leaves." When the rice-grains are observed under perfect conditions, with a good instrument, and by an acute observer, they are seen to be themselves made up of smaller luminous points known as "granules." The late Prof. S. P. Langley examined closely the minute structure of the solar photosphere and depicted it with marvellous accuracy. His description of the appearance presented by the solar surface in telescopes of moderate size, is as true to-day as when it was written. "We see," he said, "a disc of nearly uniform brightness, which is yet sensibly darker near the circumference than at the centre. Usually seen relieved against this grey and near the edges, are elongated and irregular white patches, *faculæ*, and at certain epochs trains of spots are scattered across the disc in two principal zones equidistant from the solar equator. On attentive examination it is further seen that the surface of the sun everywhere—even near the centre and where commonly neither faculæ nor spots are visible—is not absolutely uniform, but is made up of fleecy clouds, whose outlines are all but indistinguishable. The appearance of snow-flakes which have fallen sparsely upon a white cloth partly renders the impression, but no strictly adequate comparison can perhaps be found, as under most painstaking scrutiny we discern numerous faint dots on the white ground, which seem to aid in producing the impression of a moss-like structure in the clouds still more delicate, and whose faint intricate outlines tease the eye, which can neither definitely follow them nor analyse the source of its impression of their existence."

Prof. Langley estimated that the granules, or ultimate visible constituents of the solar photosphere, occupy only about one-fifth of the whole surface of the sun, and it is from these that the greater part of the solar light comes.

To the untrained observer a small sun-spot looks like an accidental speck of dust upon the eye-piece of the telescope.

FIG. 12.—Photograph of the sun and sun-spots on two successive days. Notice the change of position of the spots, caused by the sun's rotation.

Close examination, however, soon shows that a sun-spot has an appearance of its own. It is not uniformly dark, but is made up of two shades, known as "umbra" and "penumbra." The umbra is a dark portion, more or less in the centre, and the penumbra is a lighter part surrounding it like a fringe.

In the majority of cases, sun-spots are very irregular in form, and may occur singly or in groups. As a rule, one of the spots of a group becomes larger and more circular in shape as the group grows old, while the smaller spots disappear.

Sun-spots are not only interesting objects to observe, but also furnish astronomers with a very important fact concerning the sun. When the positions of spots on the sun's face are noted day after day, they are found to vary. A spot just on the eastern, or left hand, edge of the sun yesterday, appears more on the face to-day, and to-morrow it will be seen to have moved still farther towards the centre of the disc. In about a fortnight after the first observation, the spot disappears over the sun's western, or right-hand, edge. The explanation of this motion of spots from east to west is that the sun is in rotation. The spots are on the sun's surface, and are carried round on account of its spinning motion. Since this is so, it is evident that the time taken by the sun to make a complete rotation can be found by determining the time occupied by a spot in moving once round. The average time is 27¼ days. Owing to the fact that the earth is a moving observatory, this is not the true length of the sun's period of rotation. We see a spot central on the sun's disc, and if we were fixed in space, the spot would regain its position after 25⅓ days. In 25⅓ days the earth travels through one-fourteenth of its yearly track. On this account the spot is not seen at the centre of the disc after this interval but to the east of it. It has to catch up to the earth, and takes nearly two days to do so and to appear once more half-way across the visible disc.

A peculiar fact with regard to the rotation of the sun is that spots near the solar equator show a quicker rate than spots observed in higher latitudes, quicker, indeed, by as much as two days. The rate of rotation, as deduced from observations of spots, thus decreases from the solar equator. This fact has a very important consequence. It shows

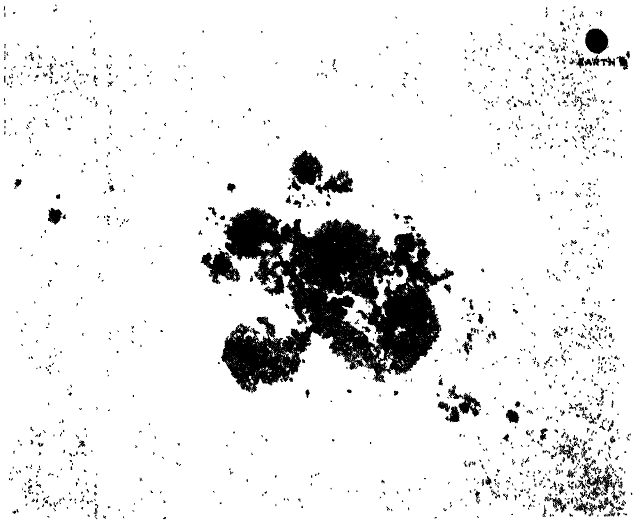


FIG. 13.—A group of sun-spots photographed at the Mount Wilson Observatory, Pasadena, on August 8, 1917. The spot at the top right-hand corner shows the earth on the same scale.

that the sun cannot be a solid globe, for if it were the rotation period would be the same in all parts. Unfortunately, there is no opportunity of studying the rate of spot movement near the poles. On very rare occasions, small spots are seen midway between the equator and poles, but none appear in higher latitudes than this. In the vast majority of cases, spots are only seen between the limits of two bands extending from five degrees to forty degrees

in the north and south solar hemispheres. The parts of the sun's surface thus favoured by spots are known as the "sun-spot zones."

Sun-spots appear dark on account of the dazzling brightness of the background upon which they exist. As a matter of fact, if a spot could be isolated from the sun, the darkest part would be found to have a brilliancy greater than that of the lime-light used in lantern illustrations. Not only are sun-spots darker than the surrounding surface: they are certainly cooler. They often have the appearance, also, of hollows or cavities, but it cannot be said to be proved that they are always depressions on the surface of the sun.

The sizes of sun-spots differ greatly, and the greatest length of the majority may be anything between 500 and 40,000 miles. Occasionally giant spots are on view. One of the largest was visible on the sun in August, 1917. It was a vast disturbance of extremely complex structure, with a few smaller spots in attendance. The area of the large spot amounted to more than three thousandths of the entire visible hemisphere of the sun. In other words, it covered more than 3,600 millions of square miles of the sun's surface. Sixteen other groups, much smaller in size, were also to be seen on the sun at the same time, and the total area covered by all the spots was no less than 6,700 million square miles; that is to say, 135 bodies of the same size as the earth would be required to cover up the immense gap. This disturbance has never been equalled in total area on any day during the whole of the photographic records.

From what has been already said, it will have been concluded that sun-spots are not permanent blotches on the sun. They appear, live a life of usefulness to astronomers, and then disappear. The average duration is a month or so. Some fade away when a few days old; others go off suddenly in their prime but the majority grow to maturity, and then die away gradually. In one or two

cases, spots have persisted for more than twelve months, but it is rarely that such a long duration is reached.

A number of bright fragments or shreds known as "faculæ" can usually be seen on the sun, especially near sun-spots, and become conspicuous when not far from the

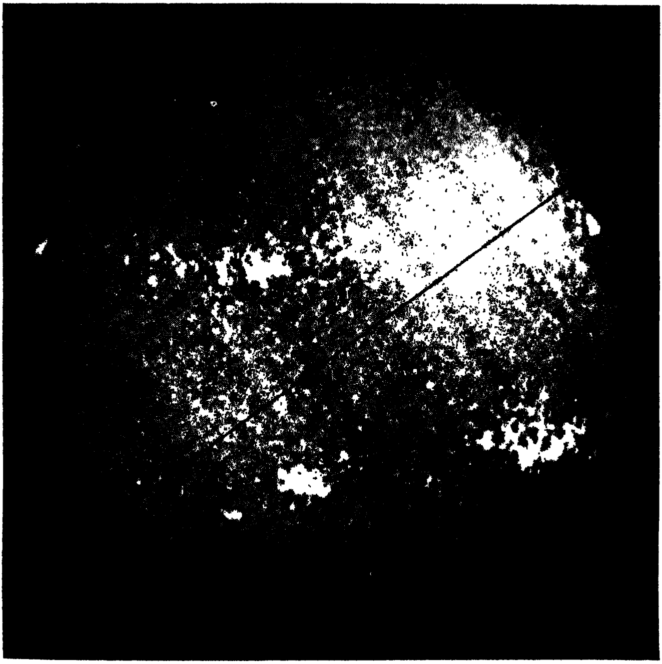


Fig. 14.—Photograph of sun showing calcium clouds or faculæ, taken at the Solar Physics Observatory, South Kensington, on September 20, 1904.

sun's edge. Faculæ are elevated portions of the sun's visible surface. A direct proof of this lies in the fact that they have been seen as slight projections on the edge of the sun. But it must not be supposed for a moment that faculæ are permanent mountains on the sun. "They

flow from form to form" in a few hours or days, and are frequently so evanescent that it is almost impossible to sketch them. Faculæ have not an established promenade across the sun, as have the spots. Excepting the polar regions, they are distributed pretty uniformly all over the surface, and by observation of them it becomes possible to find the rate of the sun's rotation in regions beyond the spot zones.

Schwabe, a native of Dessau, commenced his observations of the sun in 1826, with the idea that the labour "might be rewarded by the discovery of a planet interior to Mercury." He was then led to inquire into the rotation of the sun as indicated by the spots. Each spot was noted and numbered in the order of its appearance, and when this system of registration had been carried on to the end of 1843, Schwabe modestly remarked that the number of spots visible upon the sun varied periodically, waxing and waning in what seemed to him to be a period of about ten years. But the subject attracted little attention, and it was not until 1851 that astronomers began to wake up to its importance.

In 1857 the gold medal of the Royal Astronomical Society was presented to the indefatigable observer of Dessau. "Twelve years," remarked the President of the Society in his address, "he spent to satisfy himself, six more years to satisfy, and still thirteen more to convince mankind. For thirty years never has the sun exhibited his disc above the horizon of Dessau without being confronted by Schwabe's imperturbable telescope, and that appears to have happened on an average about 300 days a year. So, supposing that he observed but once a day, he has made 9,000 observations, in the course of which he discovered about 4,700 groups. This is, I believe, an instance of devoted persistence (if the word were not equivocal, I should say pertinacity) unsurpassed in the annals of astronomy. The energy of one man has revealed a phenomenon that has eluded even the suspicion of

astronomers for 200 years! Let us hope that the example will not be lost. Men are apt to speak of astronomy as an exhausted science, meaning that all that can be known is known. No doubt being the most perfect, it is in one sense the most exhausted science. But the astronomer of Dessau has taught us that there are still mines rich in ore, though they lie deep buried, and must be worked with more assiduity and with more care. I can conceive few more unpromising subjects from which to extract a definite result than were the solar spots when Schwabe first attacked them."

Since the delivery of this address many years have passed, and the evidence obtained during this period has been used to elaborate Schwabe's discovery. The average period or interval in which spots ebb and flow, so to speak, is found to be rather more than eleven years and a month. An important fact is that the decrease always takes longer than the increase of spottedness. In the year 1912 there were 250 days on which not a single spot was seen upon the sun. This represented a "minimum" of solar activity, for spots afterwards began to appear with greater frequency. The numbers continued to increase, and about the middle of 1917, that is four and a half years after the minimum, the activity of the sun, as evidenced by the spots, was at a maximum. The great outburst previously described marked approximately the time of this maximum. Instead of increasing in numbers, a decrease then occurred, and is still in progress, with the result that in 1923 the state of the sun in 1912 was reached again. The rise to maximum takes about four and a half years, and the fall to minimum a little more than six and a half years.

Numerous more or less successful attempts have been made to establish a relation between terrestrial phenomena and solar spottedness. On the face of it, it would appear that the temperature of the earth must vary according to the number of spots on the sun, for it has been proved

directly that spots are cooler than the surrounding photosphere. This being so, when a large spot is on the sun, the total amount of light and heat received must be different, but the difference cannot be detected, and whatever the direct effect may be it is generally obscured by vicissitudes of the weather due to local circumstances. Leaving individual spots out of the question, several investigators have produced evidence that the meteorology of our planet fluctuates with the periodic variation of solar activity. The temperatures of a few regions not subject to irregular variations have been proved to be slightly below the average when the sun is most spotted, and above the average when it is least spotted. Upon first considerations, this is the kind of result one would expect, the argument being that the greater the number of spots, the less must be the amount of light and heat emitted by the sun. But it must be remembered that an increase in the frequency and extent of spots means an increase of solar activity. Indeed, there is little doubt that the sun is hotter, as a whole, during a maximum than during a minimum period of the solar cycle of changes, and the reverse indication obtained from a discussion of the heat received by the earth must therefore be added to the long category of unexplained facts.

Sir Norman Lockyer and his son, Major W. J. S. Lockyer, discovered periodic variations in the atmospheric pressure over large areas of country such as India and Australia. The pressure is sometimes in excess of the average and sometimes below, and this difference varies fairly regularly with a period of about three and a half years. It appears that this variation must have an extra-terrestrial origin, since the effect is world-wide, and curves of atmospheric pressure variation at widely separated places show a remarkable similarity. The change is, however, in opposite directions in different hemispheres. For example, when the pressure is above the average in India it is below the average in America, and vice versa. An examination of the sun-spot

and other records shows that there are outbursts of solar eruptions, combined with a change in the general position of the spots on the sun, roughly every three and a half years; and these outbursts coincide very closely with the pressure variations on the earth. Similar atmospheric changes, of much longer period have also been discovered by Sir Norman and Major Lockyer, and these correspond fairly well with the chief eleven-year period of solar-activity already mentioned. The principal effect of these pressure variations is on the rainfall, so that droughts and famines may be indirectly produced. It is, therefore, evident that the solar spots and eruptions may have an important connexion with our terrestrial affairs, although at present the relation is not by any means well defined and cannot be relied upon to give forecasts of any practical value.

Apart from the variations produced by the presence of sun-spots, Dr. C. G. Abbot has discovered the existence of fluctuations in the actual intensity of solar radiation. This radiation may be conveniently defined by means of the "solar constant," which is the intensity of the sun's heat as it would be felt by a body outside our atmosphere when the earth is at its mean distance from the sun. Delicate instruments have to be used in the measurement of the solar constant, and, of course, the effects of the earth's atmosphere (which are extremely large) have to be taken into account. This is a difficult and somewhat uncertain matter, but by selecting observing stations at the most favourable sites it has been possible to detect and measure the changes in solar radiation. The effect of the earth's approach towards the sun in winter, and recession in summer, has been measured, and also the effect of the sun-spot cycle, which produces well-marked variations over the period of about eleven years. Irregular fluctuations of much shorter period also exist and appear to have slight effects on the climate of some places. At the present time the "solar constant" is measured daily, and the results

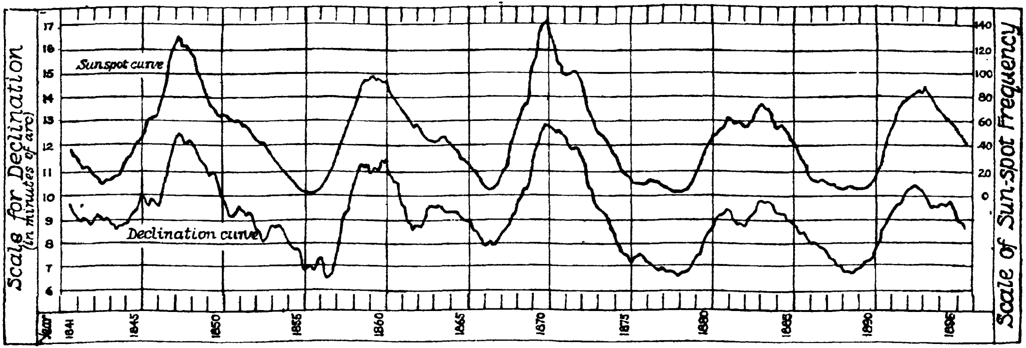


FIG. 15.—Curves showing the rise and fall of solar spottedness in an eleven-year cycle, and the corresponding disturbances of terrestrial magnetism.

obtained are found to be of some use in assisting meteorological forecasts.

The connexion between solar activity and terrestrial magnetism is much more definite than between it and meteorological phenomena. At Greenwich and elsewhere delicately suspended magnets have their positions automatically recorded throughout the day and year. An examination of these records shows that the magnets are continually wavering from side to side, and when successive years are taken, the variation from the true or average direction is found to become greater as sun-spots become more frequent, to reach a maximum soon after a maximum of solar activity and then to diminish as the spot-cycle dies out.

The two cycles run together so intimately that the connexion between magnetic variation and sun-spot frequency can scarcely be denied. This being so, a necessary consequence would seem to be that violent solar disturbances which give rise to large sun-spots, should be followed by irregular variations of the earth's magnetism, and should give rise to "magnetic storms," and in a few cases the expectation has been realized. The appearance of large spots may coincide with unusual tremors of the delicate instruments of magnetic observatories, and disturbances of telegraphic systems. The sun may thus be "caught in the act" of stirring up terrestrial magnetism. But many large spots appear without causing the magnets to flutter, while, on the other hand, violent oscillations have frequently been recorded when only a few small spots were visible on the side of the sun turned towards the earth. It seems, therefore, that the connexion between individual spots and magnetic storms may be mere coincidence, and that the actual originating cause is a solar phenomenon sometimes associated with visible spots and sometimes not. Certain it is that the sun exerts an influence of some kind upon the earth, but the influence is not in strict proportion to the number or size of the spots visible at a particular time.

Researches on this question by Major W. J. S. Lockyer, and later by Mr. J. Evershed, seem to point to the fact that the solar eruptions are more concerned in the production of these magnetic variations than are the spots. The fact that large spot groups are often accompanied by active eruptions would naturally account for the coincidences already noted. If, however, a spot or group of spots were unattended by eruptions (as sometimes happens) no magnetic storms would be observed. The apparent exceptions would thus be explained. Even this view, however, does not fully account for all the observations, and the actual originating cause of the disturbances still remains to be discovered.

The aurora borealis is caused by electrical discharges in the upper regions of the earth's atmosphere. Magnetic storms are generally accompanied by auroral displays, and vice versa. What is more, the frequency of auroræ keeps time with the frequency of sun-spots, and therefore with the intensity and magnitude of magnetic variations. The facts show that there is a general relation between sun-spots, terrestrial magnetism, and terrestrial electricity, as exhibited by observations of auroræ, but the nature of the connexion has not yet been satisfactorily worked out.

At certain intervals of time the moon comes between us and the sun and "eclipses" it. When this is the case, we are able to observe solar phenomena invisible to the unaided eye in ordinary circumstances owing to the glare of our atmosphere. Round the dark edge of the moon, scarlet-coloured eruptions of flames known as "prominences" or "protuberances" are seen to project. It was doubtful for a long time whether these prominences belonged to the sun or the moon, and they were proved to belong to the former by the observation that they were slowly covered on one edge of the sun and uncovered at the opposite edge, as our satellite changed its position. Solar prominences are parts of a stratum, to which the name of "chromosphere" is applied, consisting chiefly of hydrogen gas,

which surrounds the photosphere. In the next chapter, description is given of an ingenious method discovered independently by Dr. Janssen and Sir Norman Lockyer

FIG. 16.—Photograph of the total solar eclipse of May 29, 1919, obtained by Dr. A. C. D. Crommelin of the Royal Observatory, Greenwich. The great flame at the top left-hand extended for a distance of about 300,000 miles along the sun's edge, and at one stage of its formation reached a height of 400,000 miles.

in 1868, by means of which the chromosphere, and the prominences in it, can be studied at any time.

In addition to the prominences, a "glory" of pearly sheen is seen to surround the sun like an irregular halo when the light of the photosphere is eclipsed. To this the name of "corona" is given. For a distance of about

ninety thousand miles from the sun's edge the ring is extremely bright. Beyond this "inner corona" the

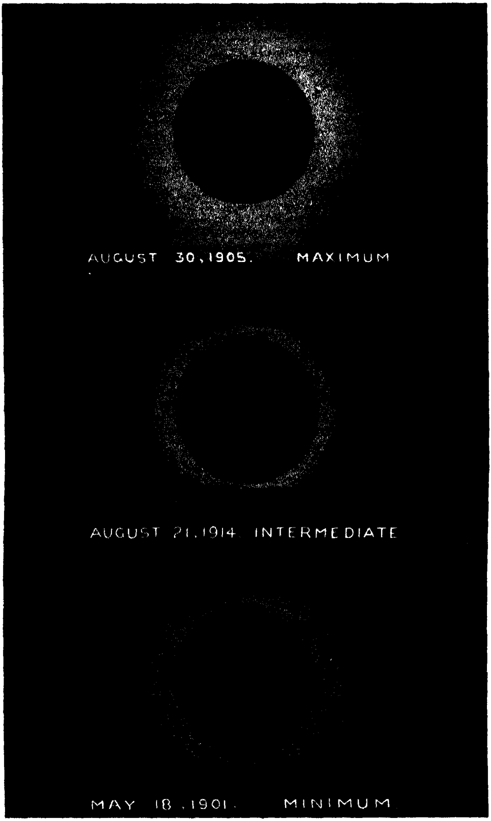


FIG. 17.—Photographs showing three typical forms of the solar corona.

"outer corona" extends in luminous streamers and sheets for distances reckoned in millions of miles, fading slowly and beautifully into invisibility. At one time astronomers inclined to the idea that the corona was not an actual

solar atmosphere, but an optical effect produced by the earth's aerial envelope. That this is not the case is definitely established by two facts. In the first place, the corona has been analysed and found to consist partially of luminous gas; and secondly, photographs of the corona taken at different places during a solar eclipse have practically the same appearance.

Drawings of the same corona can scarcely be regarded as furnishing any very definite information as to the form assumed at the time of observation. The discrepancy between the pictures drawn by two observers is frequently so great that it is difficult to believe the same phenomenon has been delineated. Photography has now almost entirely taken the place of visual observations of coronal forms, and the results can be relied upon to a greater extent. An interesting fact, which comes out from an examination of the photographs which have been taken from time to time, is that the form of the corona is connected with the eleven-year sun-spot cycle. Three distinct types of corona appear regularly in the same order during each eleven-year period. The first occurs at times of sun-spot maxima and is termed the "irregular" or "polar" type from its irregular shape. It extends almost equally in all directions round the sun except for short streamers which are usually found near the poles. The eclipse photographs of 1919 showed a corona of this type, and most of the coronas which have been photographed at or near a time of maximum solar activity have been found to resemble this very closely. The second, or "equatorial," type occurs near epochs of sun-spot minima. In coronas of this class the bright inner corona surrounds the sun fairly regularly; but over the regions of the solar equator are seen beautiful, curved streamers of great delicacy extending to very great distances from the sun. These are definite in outline, and are usually quite symmetrically placed. The corona of 1914 may be regarded as typical of this class, though most photographs at times of sun-spot minima are very similar in character.

During the periods between the times of maxima and minima, coronas of the third or "intermediate" type are usually seen. In this case, instead of two streamers, as in the equatorial type, there are four. These are symmetrically placed, and occur roughly half way between the poles and the equator of the sun. Sometimes they are very short, and result in a square appearance of the corona.

The different forms of the corona are closely connected with the solar prominences, since it has been found that the streamers lie over regions in which these eruptions most frequently occur. These regions of greatest prominence activity vary in a similar way to the sun-spots during the eleven-year cycle. At sun-spot maxima the prominence activity is great in high solar latitudes, thus producing the polar type of corona; whereas at a minimum the greatest activity occurs at about mid latitudes, and the streamers from the north and south hemispheres tend to combine and produce the characteristic equatorial extensions. During intermediate periods there are two centres of prominence activity in each hemisphere, which combine in a similar manner to produce the four streamers or "square" type of corona.

During a total eclipse of the sun, the bright stars in the part of the sky upon which the sun is projected can be photographed with the corona. Much attention is now given to such photographs because of their bearing upon the theory of relativity conceived by Prof. Einstein. By this theory a ray of light from a star must be deflected when passing the sun; and the predicted amount of the deviation is one and three quarter seconds of arc. Photographs taken during the eclipses of May, 1919, and September, 1922, showed that the positions of stars upon them were displaced by this amount outwards from the sun's centre and thus afforded a remarkable verification of Einstein's prediction.

The sun sends out its light and heat in all directions, and only a fraction of it is intercepted by bodies in the

solar system. About 2,200 million times more heat and light is given out by the sun than is received by the earth. Notwithstanding this, all known substances can be driven into vapour in the focus of a powerful burning glass; and since it is impossible for the temperature at a focus to approach that of the source of heat, it must be concluded that the sun is very hot indeed—hotter than any fire, hotter even than the electric furnace. Our atmospheric envelope robs the sun's rays of much of their fierceness; nevertheless, the amount of heat actually received would melt every year a layer of ice surrounding the earth to a depth of about fifty yards.

An impressive illustration of the intensity of radiation at the sun's surface is given by the late Professor C. A. Young. He says, "If we could build up a solid column of ice from the earth to the sun, two miles and a quarter in diameter, spanning the inconceivable abyss of 93 million miles, and if then the sun should concentrate his power upon it, it would dissolve and melt, not in an hour, not in a minute, but in a single second; one swing of the pendulum and it would be water, seven more and it would be dissipated in vapour . . . to produce this amount of heat by combustion would require the hourly burning of a layer of anthracite coal, more than sixteen feet thick, over the entire surface of the sun—nine-tenths of a ton per hour on each square foot of surface—at least nine times as much as the consumption of the most powerful blast furnaces known to art."

It has been calculated that, at this rate, the sun would burn out in less than 6,000 years if composed of solid coal. But the sun's heat is not kept up by combustion—no "burning" goes on in the sense that we use the word. Several theories have been put forward as to the manner in which the heat of the sun is maintained. One is that the sun is constantly being bombarded by meteorites, the result of the impacts being the development of heat and light. This is probably true to some extent, but if meteorites

fell into the sun in sufficient quantity to keep up the present rate of solar radiation, they would make their presence more clearly felt upon the members of our system.

Another theory of solar conservation is that the sun is slowly shrinking in size. Such a contraction necessarily involves the development of heat, and it has been shown that the supply could be kept up by a yearly decrease of 300 feet in the sun's diameter. A test of this theory would seem to be obtained by measuring the diameter of the sun year by year. But though astronomers are used to measuring very minute amounts, it must be confessed that the sun would have to go on shrinking for nearly 10,000 years before its change of size would come within the bounds of detection. It seems very probable, however, that the shrinkage of the sun and its bombardment by meteorites help one another in keeping up the supply, though even their combined effect is probably inadequate to account fully for the radiation during the enormous length of time which is suggested as the probable age of the sun by geological research. The discovery of Radium, and the enormous evolution of heat which accompanies its disintegration even in comparatively minute quantities, suggests a possible storehouse of energy which would be amply sufficient to supply the surplus heat required when all other sources have been drained.

The latest theory to account for the maintenance of the sun's heat, is a modification of the radio-active source combined with the shrinkage theory. It proceeds upon the principle that all elements (not only radium) possess a large store of energy locked up in their atoms. The exact nature of this "atomic energy" is not perfectly known, and it is not obtainable by ordinary means, but when the atoms are broken up (or "ionized") as these may be at very high temperatures, this energy is released in the form of heat. In the case of the sun then, if a sufficiently high temperature be reached at any time, some of this atomic energy may be released. The first effect

of this will be to raise the temperature of the sun, and cause it to expand. This expansion, however, necessarily involves a cooling of the sun, so that the paradoxical effect is reached that although the total amount of heat is increased, the actual temperature is lowered. The supply of energy is thus cut off for the time being; but now the shrinkage theory comes into play. With the loss of heat due to radiation the sun will contract and, as already mentioned, will grow hotter. After a time the temperature will be reached at which more atomic energy is set free, and so the whole process will be repeated time after time until this store of energy is exhausted. Shrinkage will then perhaps be the only available source.

CHAPTER IV

THE ANALYSIS OF SUNLIGHT

IN the whole domain of science there is no more wonderful achievement than that of determining the nature of the substances in the sun and stars. A century ago the feat was thought to be beyond the reach of human possibility. Since then, the science of celestial chemistry has been founded, with the "spectroscope" as its weapon of research, and the performances of the instrument have been so numerous up to the present that the whole of the previous astronomical knowledge becomes small in comparison. Especially is this the case with the sun. We see a luminous globe. Is it a ball of fire, or is its light similar to that of a glow-worm? What are the flaming prominences seen during a solar eclipse? and the corona, of what is it composed? These are the kinds of solar problems upon which the spectroscope has thrown light; and in this chapter we purpose describing the instrument which has opened up the new fields of inquiry, and some of the surprising results that have been attained.

But before going further, let us clearly understand the meaning of chemical analysis. The term signifies the breaking up of substances into their component parts. By passing a current of electricity through water, the liquid is decomposed, or broken up, into two gases known as oxygen and hydrogen. By proper means the two gases can be caused again to combine and become water. Evidently, then, water is a compound substance formed by the union of oxygen and hydrogen. They are the parts of the liquid which cannot be decomposed further, and such

parts are known as "elements." Gold is an element, for nothing but gold can be obtained from it; so is iron, and lead, and sulphur; but salt is a compound, for it can be broken up into two elements known respectively as sodium and chlorine.

There are thousands of different kinds of substances upon the earth, but chemists find that they are all combinations of about ninety elements, many of which are extremely rare. This is not very strange after all. The thousands of words in our language are all compounds or combinations of the twenty-six letters of our alphabet. Chemical compounds are therefore analogous to words, and the elements that form them are analogous to the alphabet. A compound containing two elements is similar to a word of two letters; one into the composition of which three elements enter is like a word of three letters, and so on. The chemical analysis of a substance means the determination of the elements which exist in it. How this end is attained by the chemist does not concern us here. The important point is that a portion of the substance has to be taken into the laboratory and subjected to all kinds of processes before a chemist is able to give an opinion upon it. But we cannot obtain a sample of the sun or a star to work upon, hence it would appear that no amount of searching could enable us to find the elements existing in these bodies; yet celestial chemistry is an accomplished fact. It is not at all necessary to send chemists prospecting into space, and to bring back portions of the worlds they visit. The spectroscope furnishes a means of analysing bodies by the light they emit; it enables astronomers to decompose the beams of light continually sent to us by the sun and stars, and to say to what element a ray belongs.

Every one has seen the varied colours produced when sunlight is shining upon the lustres of a chandelier. Each pendant piece of cut glass forms a band coloured like the rainbow. Sunlight, then, is not an elementary colour, for it can be broken up into a number of different colours.

4

To investigate this more closely, let a large lustre, or a wedge-shaped piece of glass known as a "prism," be placed in the path of a beam of sunlight entering a dark room through a small hole so that the rays fall upon one of its faces. Two facts will be noticed with regard to the beam when it has passed through the prism. In the first place, instead of keeping in its original direction, the beam is bent or refracted towards the base of the prism, and next, different colours are bent by different amounts, the result being that a coloured ribbon, known as a "spectrum" is produced. The colour least bent is red, then follows orange, then yellow; the next is green, the next blue, the next indigo, and the most bent colour of all is violet.

These tints always preserve the same relative positions, that is, they always follow each other in the same order. If the red colour is subtracted from the beam before it falls upon the prism, no red appears in the spectrum, and the same applies to any other colour. In fact, the coloured band is produced by the overlapping of a large number of different coloured images of the hole through which the beam enters. If seven pieces of glass, coloured respectively red, orange, yellow, green, blue, indigo, and violet, are placed in a line, so that they overlap one another, each of the colours produced by the overlapping will be a mixture of two. If, however, the glasses are placed side by side in a row, no such impurity of tint is caused. In a similar manner, the overlapping of the images of the aperture, which admits sunlight to the prism, causes the spectrum to be "impure." Each elementary tint should be ranged by the side of the next, passing by insensible gradations from the deepest red to the darkest violet. To obtain this result, a fine crevice or slit is employed instead of a hole. A slab, instead of a rod of light, falls upon the prism, and a spectrum, in which an infinite number of shades are ranged side by side, is produced. We are thus furnished with an accurate scale of colour, which can be viewed with the naked eye or through a small telescope.

In a spectroscope the slit for admitting a beam of light, the prism for decomposing the light, and the telescope for viewing it, are arranged in a compact form. Fig. 18 shows such an instrument in its simplest form. The tube upon which the maker's name is marked has a slit at the end away from the prism, and the other tube is the view-telescope.

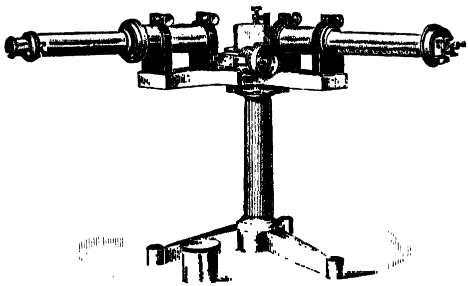


FIG. 18.—A simple spectroscope made by Messrs. Adam Hilger, Ltd.

A spectroscope is thus an instrument to analyse light. Many substances, when burnt, have such distinctive colours that no instrument is needed to discriminate them. Thus, common salt or soda tinges the flame of a spirit-lamp yellow. Red fire, or a red Guy Fawkes's match, owes its colour to the presence of a chemical containing the element strontium; green fire, or a green match, contains the element barium. Hence, when we see a red firework or a green-coloured one, we are able to state, with more or less certainty, that strontium or barium is being burnt. But this can by no means be applied to celestial bodies. The sun is a glowing mass, and, so far as observations with the unaided eye are concerned, it could be a ball of iron, or of gold, or of silver, or anything else. We cannot determine the quality of its light by ordinary observation as can be done with simple fireworks. Indeed, only a few coloured fires can be distinguished in

this manner. Generally half a dozen or more powders are mixed together, and the light they give when ignited is a mixture in which the colours due to individual elements are lost.

The spectroscope here comes to our assistance. The yellow light due to the burning of common salt is caused to illuminate the slit of the instrument it falls upon, and traverses the prism and forms a yellow image. When observed with the view-telescope, the image is seen to consist of two fine yellow lines, very close together. Now let the red light of strontium fall upon the slit. It traverses the prism and forms red images—images not so much bent out of the original direction as the yellow lines are—and a blue image, that is, one more bent. The light of burning barium causes a large number of brilliant lines and bands to be seen, some more bent and some less bent towards the base of the prism than the yellow lines exhibited by common salt. Lithium shows a red line—a line less bent out of the original direction than any of the others.

If a number of substances are burnt together in the flame of a Bunsen burner, each of them shows the same lines or bands as they do when burnt separately. The prism assigns particular positions to be taken up by the light of each element, and an observer soon gets to know these positions. He is thus able to distinguish the lines or badges of different substances in much the same way that a military man can pick out soldiers of different regiments during a review, or name the various ribbons of war medals.

Different elements, then, exhibit different sets of lines when observed with the spectroscope. Some elements show only one or two lines, while others show a large number under similar conditions, but each element has a set of its own, whether the lines are few or numerous. This fact can be utilized to determine the elements in a mixture. The substance which it is desired to analyse is burned in a flame of some kind, or otherwise rendered

luminous, and then observed through the spectroscope. "Yes," says the observer, "there are the lines of sodium, close to them are the strontium lines, and there is the green line of thallium"; and he continues his observations in this manner until the origins of all the lines have been recognized.

When a gas flame, or the light of an ordinary lamp, or the incandescent ball of lime used for lantern illustrations is observed with a spectroscope, an unbroken band of colour known as a "continuous spectrum" is seen. The light of every white-hot solid or liquid body, or of any luminous gas under pressure, is transformed by the prism into this rainbow-coloured band.

We have said that a little salt placed upon the wick of a spirit-lamp tinges the flame yellow and causes a pair of bright lines—the "sodium lines"—to be seen in a spectroscope. If, while the lines are under observation, a lime-light is started, so that its bright beams have to pass through the sodium flame to reach the slit of the spectroscope, they will be seen not *bright* as before, but as *dark* lines upon a continuous spectrum. Turn off the incandescent light, or block it out by means of a screen, and the sodium lines are again seen bright and alone. The flame is not altered by the light passing through it. We must therefore conclude that the lines are seen dark by contrast with the bright continuous spectrum of the lime-light. By placing lithium, or thallium, or any other substance upon the flame, and passing the beams from the incandescent cylinder of lime through it, each set of lines is seen dark upon a coloured ribbon instead of appearing as bright and differently coloured images of the slit. Thus, each element burning in the flame blocks out from the continuous spectrum the lines of which its own spectrum consists. This is a most important observation; indeed, it is the cardinal principle of spectrum analysis applied to the heavens.

In 1814, Fraunhofer, a German optician, found that by

admitting sunlight to a prism through a crevice in a window blind, and viewing the spectrum with a small telescope, the coloured band was crossed by a number of dark lines at right angles to the direction of its length. He counted about six hundred lines, and mapped the positions of something like half this number, designating the most conspicuous lines by letters of the alphabet. With the spectroscopes now at the disposal of astronomers thousands of dark lines can be seen in the spectrum of sunlight. In honour of the discoverer they are termed "Fraunhofer lines." Fraunhofer found that the line, or rather pair of lines, produced by burning common salt, occupied exactly the

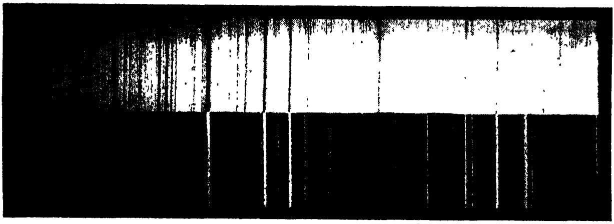


FIG. 19.—Photograph of part of the solar spectrum (top) compared with the corresponding part of the spectrum of iron. The coincidences of lines in the two spectra show the presence of iron in the sun.

same position as a dark line in the solar spectrum, but the circumstance was regarded more as an accident than otherwise. Not until nearly half a century later, in 1859, was the key to these enigmatical lines discovered. It is involved in the third principle experimentally illustrated above and enunciated by Kirchhoff. What Kirchhoff said in substance was this: "There is a solid or a liquid something in the sun giving a continuous spectrum, and around this are vapours of sodium, of iron, of calcium, of chromium, of barium, of magnesium, of nickel, of copper, of cobalt and aluminium; all these are existing in an atmosphere, and are stopping out the sun's light. If the sun were not there, and if these things were observed in an incandescent

state, we should get exactly these bright lines from them."

The conviction is thus forced upon us that the dark lines in the solar spectrum are caused by light from a very hot body having a continuous spectrum, passing through an envelope of gases at a lower temperature. Each gas subtracts from the continuous spectrum those rays of which its own spectrum consists; hence, by matching the dark lines in the solar spectrum with bright lines of terrestrial elements we can determine the chemical constitution of the atmosphere which produces them. The comparison is best made by burning substances in the electric arc, for we then see them at a temperature approaching that of the sun. Sunlight is caused to illuminate one half of the slit of the spectroscope, while the light of the arc illuminates the other half. The solar spectrum, and the "arc spectrum" of the substance being burned, are then seen one above the other, and the coincidence or non-coincidence of dark lines of the former with the bright lines of the latter can be made out. But the photographic plate has now almost entirely replaced eye-observations of this kind. The two spectra are caught upon a sensitized plate, and the lines leave their impressions upon it. The pictures can then be examined at leisure to see if Fraunhofer lines are matched by lines due to the substance burning in the electric arc.

The visible solar spectrum is a coloured band extending from red to violet, and it might be concluded that this strip represents the beginning and the end of it. But if a photographic plate be placed so that one end lies in the red part of the spectrum and the other reaches beyond the violet, and after being exposed for a short time it is taken away and developed in the usual manner, what do we find? Lines more bent than the violet end of the spectrum appear upon the photographs, that is, lines which are altogether invisible to the eye. The lines in the violet and blue parts of the spectrum are also

portrayed in their proper relative positions; but unless the film has been specially prepared, none of the lines from the green to the red are found upon the pictures. The photographic plate is thus sensitive to light rays which are incapable of producing any visual effect, and the eye, on the other hand, can see rays which leave no impression upon an ordinary sensitive film.

Photographic and visual comparisons of this kind have shown that most of the elements existing upon the earth are to be found in the sun. More than two thousand lines contained in the spectrum of iron coincide with the same number of dark lines in the solar spectrum. What is more, brilliant lines of iron are represented by conspicuous Fraunhofer lines; while faint lines in the spectrum of the metal have faint counterparts. According to the most recent observations the common terrestrial elements at present known to enter into the sun's constitution are given in the following table:—

Iron	Calcium	Silicon	Zinc
Nickel	Neodymium	Hydrogen	Copper
Titanium	Scandium	Strontium	Silver
Manganese	Lanthanum	Barium	Glucinum
Chromium	Niobium	Aluminium	Germanium
Cobalt	Molybdenum	Calcium	Tin
Carbon	Yttrium	Rhodium	Lead
Vanadium	Palladium	Erbium	Potassium
Zirconium	Magnesium	Oxygen	Helium
Cerium	Sodium		

In addition to these elements there are several others that are suspected to be present, though the evidence on this point is not absolutely conclusive. It will be noticed that several important terrestrial elements are not included in the above list. Among these are sulphur, nitrogen, phosphorus, arsenic, and the elements of the "halogen" group—chlorine, bromine, iodine, and fluorine. It must

not be assumed, however, that these elements are actually absent from the sun, since it is quite possible for them to occur in certain regions of the sun without giving any evidence of their presence. Experiments in the laboratory show that many of these elements when mixed with metallic vapours fail to exhibit their characteristic lines in the spectrum of the mixture. It is therefore very probable that all known terrestrial elements are to be found in the sun, and there is little doubt that if the earth were heated to the temperature of the sun its spectrum would closely resemble the solar spectrum.

It was at one time thought that the Fraunhofer lines are produced by absorption in our own atmosphere and not in the solar envelope. If this were so, the lines should increase in strength when sunlight traverses a greater thickness of atmosphere, that is, in the morning or evening. There should be a gradual decrease in intensity from sunrise to noon, and an increase from noon to sunset. Only few lines really show this variation; these are therefore produced by our atmosphere, and are known as "telluric lines."

So far we have dealt only with the summation, as it were, of solar light. In 1866, Sir Norman Lockyer suggested that different parts of the sun should be examined in order to obtain an intimate knowledge of solar phenomena. An image of the sun, formed by means of a lens, is caused to fall upon the slit of a spectroscope. If it is desired to observe the spectrum of a sun-spot, the sun's image is arranged so that the spot is on the slit. Upon observing the solar spectrum when this is the case, a dark strip is seen to stretch from one end to the other. Many of the Fraunhofer lines are seen to be thickened or widened where the dark strip crosses them, while others are unaffected. We have seen that the lines owe their existence to the absorbing effect of a comparatively cool envelope. If, therefore, the amount of absorption is increased, the lines must appear wider. Hence the widening of Fraunhofer

lines where the dark strip crosses them is an indication of increased absorption, and this can be produced either by a decrease of temperature or an increase of pressure, or both. By observing the set of lines that are affected, the kinds of vapours existing in the spot are determined. Occasionally Fraunhofer lines in a spot-spectrum become suddenly bright, thus indicating that the vapours they represent have been suddenly increased in temperature or decreased in pressure, or projected above the level of the absorbing layer.

The spectroscopic observation of prominences during the total solar eclipse of 1868 showed that these fantastic forms chiefly consist of glowing hydrogen, the most conspicuous lines in their spectrum being due to this element. In addition to the lines of hydrogen, a bright line was also observed in the yellow part of the spectrum, very near, but not quite coincident with, the two yellow lines of sodium. At that time no terrestrial element was known to produce a line in this position, although some of the stars showed it and other lines which appeared to be due to the same element. Apparently, therefore, it was unknown on the earth, and was accordingly named "helium" by Sir Norman Lockyer; but in 1895, during some experiments with the mineral cleveite, Sir William Ramsay discovered this yellow line in the laboratory spectra, so that it soon became evident that helium was one of the gases liberated by this mineral, and must be numbered among the terrestrial elements. Large quantities of helium gas are now being obtained from natural gas in the United States, and are being compressed in cylinders for use in airships. The gas is non-inflammable, so than an airship inflated with it cannot be set a-fire.

Fortunately for science, Dr. Janssen and Sir Norman Lockyer independently discovered in 1868 a means of observing prominences at any time. The principle of the method is as follows: We are unable to see the stars in the daytime on account of the glare of

sunlight in our atmosphere, and the prominences and corona are invisible in ordinary circumstances for exactly the same reason. If the earth were deprived of its aerial envelope, the stars, prominences, and corona would be seen against the dark background of space in the daytime. Evidently, then, if the intensity of the atmospheric glare can be diminished without a corresponding diminution of the light of the prominences, these red flames will become visible. The spectroscope permits this to be done. The spectrum of diffused sunlight is the same as that of the sun itself. When an instrument having a single prism is used to view this spectrum, the characteristic coloured ribbon of light is seen. With a two-prism spectroscope the ribbon appears of a greater length, but fainter in all its parts; a three-prism instrument shows it stretched still more, but the extension has again been accompanied by a loss of brightness. Thus the intensity of the spectrum of diffused sunlight diminishes as a spectroscope is increased in power. But consider what happens when the spectrum of the glowing hydrogen prominences, which consists of a few bright lines, is similarly observed. When observed with a single-prism spectroscope these lines occur at certain distances apart. A two-prism instrument separates the lines to a greater extent, without altering the relative distances. A three-prism instrument makes the intervals still greater, and so on for any number of prisms, each adding its separative effect to the one before it.

It appears, therefore, that an increase of the power of a spectroscope diminishes the intensity of atmosphere glare without diminishing the brilliancy of the bright lines of which the prominence spectrum consists. Hence, if the slit of a powerful spectroscope is placed near the sun's edge, so that the continuous spectrum seen is that of the sky, and not of the sun itself, and a prominence happens to exist at that part of the edge, the bright lines in its spectrum will be clearly seen, and if the slit is widened

the prominence itself becomes visible. In order to observe the prominences projecting from the sun's disc at any time, the slit of the spectroscope has to be adjusted at different points until it has been taken completely round the edge. By an invention due to Professor G. E. Hale of Mount Wilson Observatory, Pasadena, California, all the red flames shooting out from the edge can now be photographed at a single exposure, or, if desired, the whole of the sun may be photographed in the light of a single wave-length. This may be accomplished by causing an image of the sun to fall on the slit of a spectroscope in a manner similar to that described for the examination of different parts of the sun. The spectrum which results, however, is not immediately photographed, but a second slit is placed in front of it in such a way as to block out the whole spectrum except one prominent line—the bright red line of hydrogen, for example. The light which emerges from this second slit is therefore that emitted by the hydrogen in that part of the sun which happens to fall on the first slit. In other words, we have a picture of a narrow section of the sun in the red light of hydrogen.

If the image of the sun is now allowed to move slowly, successive pictures of different sections are secured until the whole sun has been passed in review. A photographic plate placed in front of the second slit can thus record all these pictures; and when it is caused to move at the same rate that the image of the sun moves across the first slit each consecutive little section is recorded on adjacent portions of the plate instead of on the same part, so that the result is a complete picture of the sun in the red light emitted by hydrogen. We obtain in this way a picture of the sun painted, as it were, in a single colour instead of in the composite colours of white light. An instrument of this type is known as a spectro-heliograph and is of great value in investigating the form and distribution of clouds of hydrogen, calcium, and other gases over the surface of the sun. The solar prominences, which in the

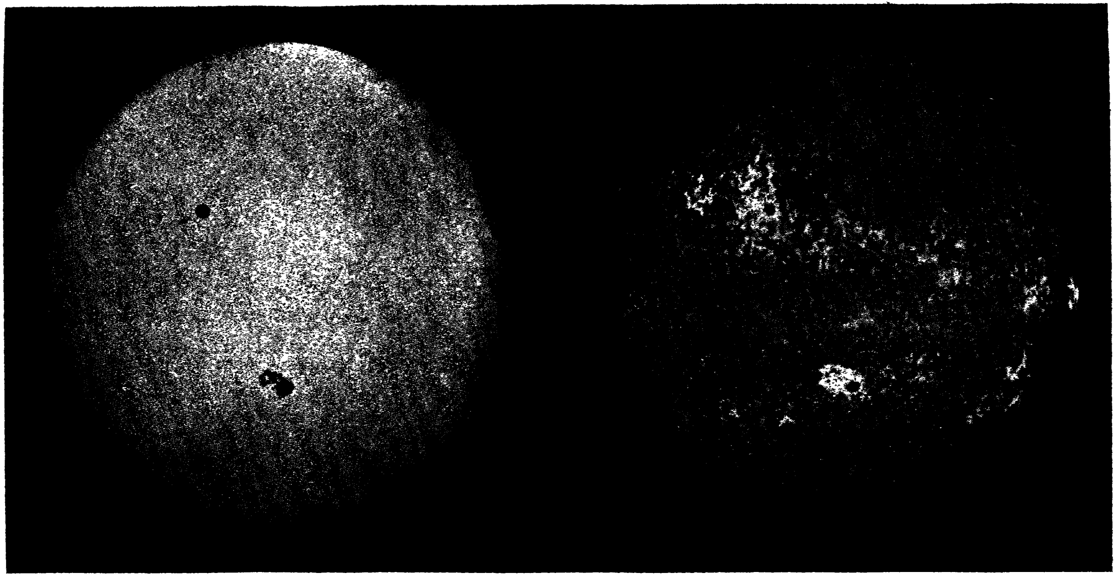


FIG. 20.—Direct photograph. Photograph in calcium light.
Photographs of the sun obtained on July 30, 1906, by Prof. G. E. Hale.

ordinary way can only be seen projecting from the edge of the sun's disc, may thus be photographed in projection against the surface of the sun.

The prominences are conveniently arranged into two groups, known respectively as "quiescent" or "hydrogen" prominences, and "eruptive" or "metallic" prominences. The former class resemble our terrestrial clouds. They are usually very large, extending to a height of 50,000 or 100,000 miles above the chromosphere, and frequently endure unchanged for days together. This class has been subdivided into "broad forms," "tapering forms," "diffused forms," and "rows of sheaves" by Dr. J. Evershed, according to their shapes. Prominences of the latter class are far more vivacious than their steady going brethren, and are less massive. They exhibit many bright lines due to metallic elements, hence the designation "metallic prominences." They are nearly always found associated with sun-spots, and are usually much smaller than the former class. They appear as solitary bright jets or arches, and are in such extremely rapid motion that their changes in form can be detected in the course of only a few minutes.

The motion of a prominence shot straight out from the sun's edge can be seen, but it is evident that if the flame were moving towards or away from us at the same time, or if it had a whirling motion, the eye could not perceive it. Fortunately, this "motion in the line of sight" can be detected and measured by means of the spectroscope. The principle is as follows:—

When standing upon the platform of a railway station towards which an express train is approaching, many people will have noticed that the pitch of the whistle *increases* slightly as the engine approaches, and *decreases* as it rushes away. The absolute pitch of the whistle is immaterial. When the distance is diminishing the pitch is raised, and when the distance is increasing the pitch is lowered. This principle also applies to light. A luminous body approaching the earth has its colour-pitch raised,

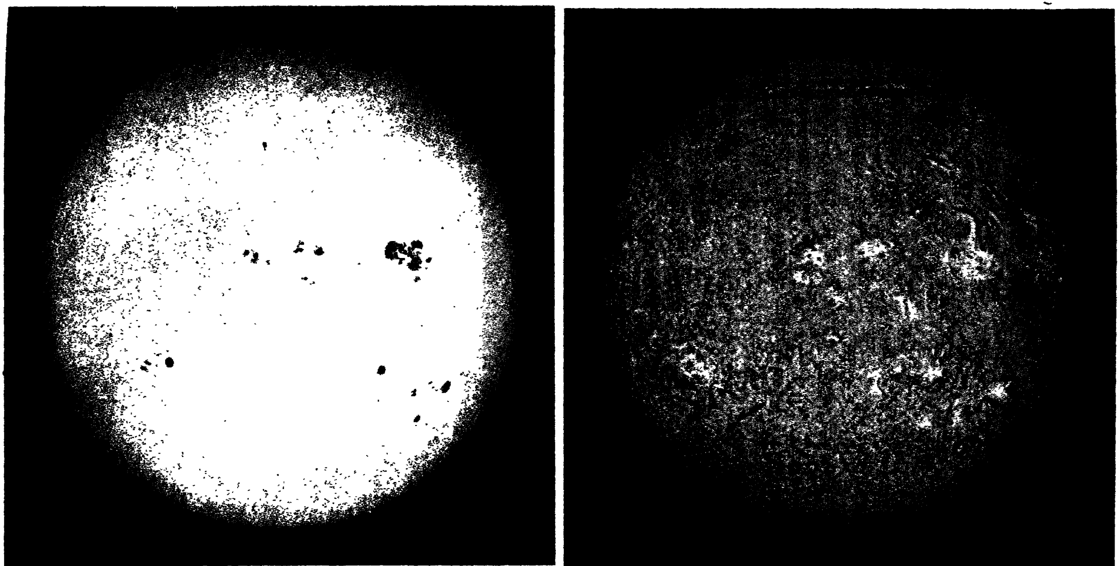
while a motion away from the earth causes it to be lowered. The positions of lines in a spectrum corresponds to the pitch of notes in the musical scale. The lowest notes of a piano correspond to red light, and the highest notes to violet light. Further, each C of the piano may be compared with a line of hydrogen in the solar spectrum. Now, the difference between the pitch of C and any other note is constant. If the piano is moving rapidly towards us, or we towards it, and all its notes are sounding, all of them will have their pitch raised, while a motion in the opposite direction causes a lowering of pitch. But if we suppose that one set of notes, say C and all its octaves, is being hurried towards us while the remainder are at rest, this set only will have its pitch increased. The difference of pitch between each C and the D next above it will therefore be diminished, and the magnitude of the difference will depend upon the velocity with which the C notes move towards us. A motion of recession causes a lowering of the C notes relatively to those at rest.

Transfer your thoughts from the musical notes to the hydrogen lines in the spectrum of a prominence. If the hydrogen to which they owe their appearance is moving towards the earth, the lines are increased in pitch; they are shifted slightly towards the Fraunhofer lines just above them, that is, nearer the violet end of the spectrum. Hydrogen moving away from the earth suffers a decrease of pitch, and the difference of distance between its lines and the lines nearer the red end of the spectrum is diminished. By measuring the difference on either side, the velocity of approach or recession of the mass of hydrogen can be calculated. Similar reasoning applies to the spectrum of a sun-spot. It sometimes happens that many of the Fraunhofer lines are considerably distorted in a spot-spectrum. Thus, the lines of hydrogen, instead of being straight, assume zigzag and branching shapes. Where the lines are bent towards the red end of the spectrum, the hydrogen they represent must be moving away from

the earth, and, on the other hand, the parts of the spot in which the gas is moving towards the earth show the hydrogen lines displaced in the opposite direction. It is only when the gas is neither approaching nor receding from us that the lines are straight.

FIG. 21.—Solar vortices, showing whirling flocculi of hydrogen gas above two sun-spots. Photograph obtained with the Spectro-heliograph by Prof. G. E. Hale.

Both in prominences and sun-spots a whirling motion has been detected, indicating that the sun, like the earth, has its " cyclones " and " tornadoes," but on a much grander scale. Some of the photographs taken by Prof. G. E. Hale with a spectro-heliograph show in the neighbourhood of sun-spots a structure which is decidedly of this nature.



A B

FIG. 22.—Photographs of the sun obtained at the Mount Wilson Observatory, Pasadena, on August 12, 1917. A, Direct photograph. B, Photograph obtained with the Spectro-heliograph, using hydrogen light only. The bright flocculi and dark filaments are both believed to represent prominences projected upon the sun's disc, the dark being hydrogen at the highest levels, and therefore cooler than the bright.

The impression conveyed is so pronounced that he has named them "solar vortices," and these vortices are rendered additionally interesting by the fact (also discovered by Prof. Hale) that they are accompanied by strong magnetic fields. This discovery was made possible by Prof. Zeeman, who in 1896 showed that if a source of light is placed between the poles of a powerful magnet the resulting spectrum lines are split up into doublets or triplets according to the direction in which they are observed. A like effect was observed by Prof. Hale in the regions surrounding sun-spots, thus proving the existence of strong magnetic fields, which he attributed to the effect of electrically charged particles being whirled round and round with the vortical motion. These discoveries are especially interesting on account of their probable connexion with the magnetic effect of the sun on the earth. The velocities shown by the spectroscope in solar phenomena are usually from fifty to about two hundred miles per second, and occasionally a rate of three hundred miles per second is measured, but this is very rarely exceeded. It is difficult to conceive of material ejected with these tremendous velocities, yet the spectroscope shows clearly that the masses of gas do actually move in this swift manner. As to the nature of the forces which produce this violent agitation, little is definitely known.

Metallic prominences are closely connected with sun-spots. They occur most frequently over the sun-spot zones, wax and wane in an eleven-year period, break out in high latitudes after a minimum of activity, and then approach the equator up to the next minimum. Indeed, all solar phenomena are connected in some way or other; and, as time goes on, the law that governs them will be revealed,

The spectroscope has been turned to the corona during the brief moments of solar eclipses, and the bright lines seen and photographed show at once that we are dealing chiefly with a luminous gas. The spectroscopic trade-mark, so to speak, of the corona is a green line coincident

with a faint Fraunhofer line in the ordinary solar spectrum. Like many other lines, this has not been matched with a line given by a terrestrial element, that is to say, no known element has a line in exactly the same position as the "corona line." The probability is that the line is due to

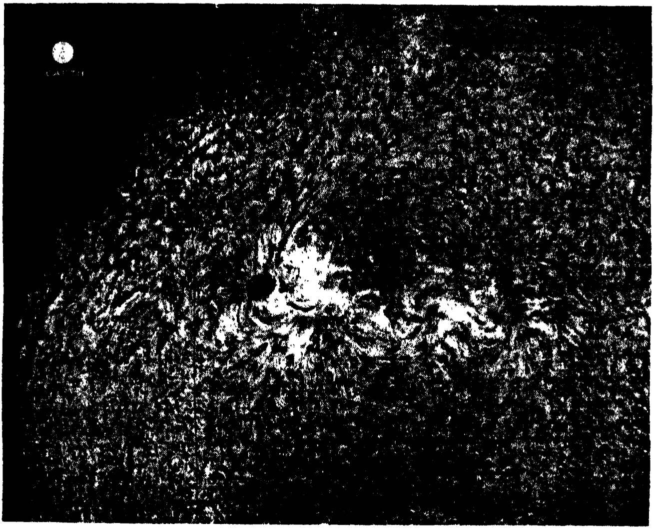


FIG. 23.—Hydrogen flocculi and filaments photographed with the Spectroheliograph at Mount Wilson Observatory, Pasadena, on January 5, 1917, by Mr. E. Ellerman. The size of the earth is shown for comparison.

a material lighter even than hydrogen, the lightest of known substances. The extremely fine—indeed, one may say, the ghostly—texture of the corona shows that the material exists in a state of excessive tenuity.

In addition to the conspicuous badge of the corona a number of other bright lines, some of which are due to hydrogen, show themselves in the spectrum. A number of dark Fraunhofer lines and a faint continuous spectrum are also seen. This indicates that some of the coronal light is

sunlight reflected by solid particles. But since no method has yet been perfected whereby this envelope or outer atmosphere can be studied in daylight, less is known about it than the prominences, which, as has been pointed out, can now be studied without waiting for an eclipse.

The physical constitution of the sun, and the causes of the various solar phenomena, have been and are still matters of discussion. The general belief is that the *nucleus* of the sun consists of gases under great pressure and at extremely high temperatures. Surrounding this is the *photosphere* or luminous surface, which is probably of a cloudy nature, but the clouds instead of being composed of particles of water consist of condensed vapours of metals. The clouds float in an atmosphere in which uncondensed vapours of metals take the place of the oxygen and nitrogen of our own atmosphere. The atmosphere extends above the level in which the photospheric clouds occur, and, by its absorbing action, produces the Fraunhofer lines in the solar spectrum. *Faculæ* are elevated clouds, and they appear brighter than the general photosphere, because their light has not to pass through such a great thickness of absorbing atmosphere. Spots are relatively cool portions of the photosphere. They are probably produced by the down-rush of large quantities of condensed matter upon the photosphere. The *granules* are the tops of photospheric clouds. The *chromosphere* extends to a height of about 5,000 or 10,000 miles above the photosphere.

The chief constituents of the chromosphere are hydrogen, and helium. The *prominences* are portions of the chromosphere which have ascended above the general level. Surrounding the chromosphere, the *coronal atmosphere* or *corona* occurs. This envelope consists partly of glowing gas and partly of solid particles, which reflect sunlight. Its chief gaseous constituent is unknown in terrestrial chemistry, and has been named "coronium."

Much has been done since the spectroscope entered the field of inquiry, but much more remains to be done. New

facts are, however, being rapidly accumulated as to the sun's constitution, structure, and variations; and as the knowledge of solar physics increases we are brought nearer to the key which will unlock the secrets of meteorological changes on the earth, all of which have their ultimate origin in the condition of the sun.

CHAPTER V

THE EARTH'S CLOSE COMPANION

THE moon is the earth's constant and close attendant. Bound to our globe by the strong attachment of gravitation, it accompanies us wherever we go. Its distance is only 240,000 miles, that is, about ten times greater than the circumference of the earth, and four hundred times less than the sun's distance. Judging by appearances, the full moon looks almost as large as the sun, but as such a great difference exists between the distances of the two bodies from the earth, it is obvious that the moon is really much smaller than the sun. The apparent sizes of objects are proportional to the distances from which they are viewed. Since, then, the moon is seen from a distance four hundred times less than the distance of the sun, and appears approximately to have the same diameter, its real diameter is four hundred times less than that of the sun, that is, one four-hundredth of 866,000 miles, or 2,165 miles. If the earth could swell in size until it reached the moon, 240,000 miles away, its diameter would only be a little more than half the sun's diameter.

The moon is a small body even when compared with the earth. About three and a half moons in a row would be required to stretch across a distance equal to the earth's diameter. North and South America taken together have more square miles than the whole of the lunar surface. As regards the volume or bulk, forty-nine moons welded into one would make a globe of the same size as the earth. But this globe would only weigh about three-fifths as

much as the earth, for the lunar rocks, taken as a whole, are not so dense as those which make up our planet. If both lunar and terrestrial materials had the same average density, the earth's mass, as well as its volume, would be forty-nine times greater than the moon's, whereas the mass of the earth is eighty-one times greater than that of the moon.

A lunar inhabitant, if endowed with the same muscular exertion as ourselves, would be able to perform remarkable feats. If he could carry one hundredweight on the earth, he could carry six hundredweight on the moon, and if he could jump three feet here, he could with the same exertion leap eighteen feet on the moon. Should a weighing-machine indicate his weight to be twelve stone on the earth, and then be transported to the moon, he would find that the change of place had brought his weight down to about twenty-eight pounds. If transport facilities existed between the earth and the moon, and we exported coal to provide warmth for the inhabitants of our satellite, a ton of coals, containing the usual quantity of twenty hundred-weight, might be started on its journey, but when the householder on the moon checked the weight by means of a spring-balance he would find that the load only weighed three hundredweight, although the actual bulk had not diminished.

The moon differs from the sun in the fact that it passes through phases or changes. First, the " New moon, like a silver bow, new bent in heaven," is seen just above the sun as it sets on the western horizon, the horns of the crescent always being pointed away from the globe from which its light is borrowed. Each night sees the crescent wider, and soon the half moon or " first quarter " is reached. A week later the full moon " rolls through the dark blue depths." Another week, and a half moon is again visible, then a crescent is seen in the dawn, with the horns pointing away from the sun, and then the old moon is swallowed up in sunlight. The time from full moon to

the next, or from any phase to the same phase again, is twenty-nine and a half days. From new moon to half moon, half to full, and so on, the intervals is, roughly speaking, seven days, and our week of seven days probably had its origin in this fact.

Lunar phases result from the fact that moonlight is reflected sunlight. One half of the moon is bathed in the sun's beams, while the other half is in darkness. When the illuminated half is facing us, the moon is full; when we view it sideways, a half moon is seen; and when the bright face is turned from us, we see no moon at all. All the changes are caused by the ever-varying aspects presented to us by the hemisphere of the moon which faces the sun.

At the time of new moon our satellite is in "conjunction" with the sun, that is to say, both bodies appear due south at the same instant. Usually the moon is slightly above or below the sun at the time of conjunction, so it does not come between us and the sun's beams. The illuminated side is then turned away from us. A few days later, the moon has moved round the earth sufficiently to show a small portion of its bright side. Seven days after new moon the first quarter of the monthly journey has been described, and we are able to see one half of the illuminated hemisphere. Seven days more, and the moon is in "opposition" with the sun, that is to say, the sun, earth, and moon are in one direction, with the earth in the middle. But the three bodies are not generally in a line, so the people on the earth are able to see the moon "in full-orbed glory," as the sunlight streams upon its face and clothes it with radiance. At the end of the third quarter the moon is once more in a direction at right angles to the sun, and a half moon is seen. From this time the visible portion of the lunar surface diminishes to new moon, when the cycle of changes begins again.

If the moon revolved round the earth in the same plane—the plane of the ecliptic—as that in which the earth

journeys round the sun, then once a month it would come between us and sunlight and eclipse the sun; so that an eclipse of the sun would occur at the time of every new moon. Similarly, at the time of each full moon, the sun, earth, and moon would be in a straight line, and an eclipse of the moon would occur as our satellite passed into the earth's shadow. These events do not happen monthly,

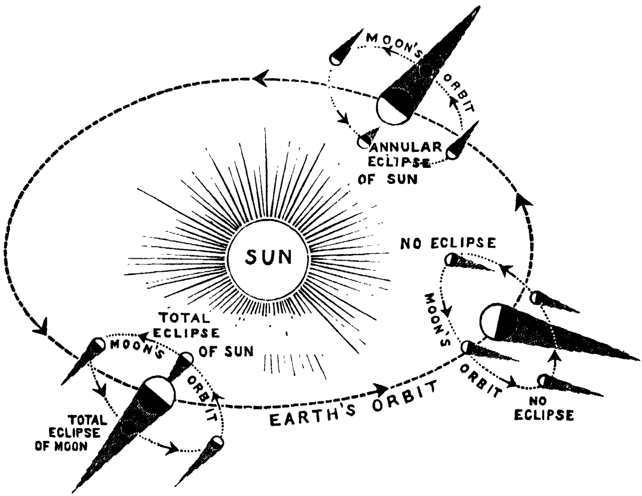


FIG. 24.—Orbits of the earth and the moon, showing the cause and character of eclipses.

because the moon does not revolve on exactly the same plane as the earth. The moon's track among the stars does not coincide with the sun's track—the ecliptic. Could two luminous trails be drawn upon the sky to represent the respective paths of the "greater and lesser lights," they would be seen to cross one another at two points, known as "nodes." The greatest distance between the two trails would be about ten times the apparent diameter

of the moon. A total eclipse can only happen when the moon is at one of the points where its orbit cuts the ecliptic. If the sun should arrive at this point at the same time as the moon, a solar eclipse must occur ; if the moon should arrive at a node just when the earth's shadow is sweeping past it, it must be totally eclipsed ; and if the three bodies should be in a line when the moon is near, but not at a node, the eclipse will be only partial.

It was noticed in very early times, that after an interval of 223 lunar months, eclipses happened in the same sequence as before ; in other words, the occurrence of eclipses follows a cycle of 18 years. The period is known as the " Saros," and by means of it the dates at which eclipses would occur were predicted by ancient astronomers. Thus, an eclipse which happens on any particular day will occur again after 223 months, or, more accurately, 6,585⅓ days. In the whole period there are about 45 solar and 25 lunar eclipses. Seven eclipses can occur in a year, and two must occur ; in the latter case, both are eclipses of the sun.

The periodical recurrence of eclipses is caused by a movement of the nodes of the moon's orbit. Reverting to the imaginary luminous tracks of the sun and moon, suppose that the two crossed each other at one point exactly in front of a star. At the end of a month the node would be found to the west of the star ; in two months it would be further to the west, and so on. After 18 years, the nodes would have backed completely round the ecliptic, and would be projected upon exactly the same part of the sky. As eclipses only happen with the moon near a node, it will be understood that the length of the lunar cycle of 223 months must be regulated by the motion of the nodes.

The phenomena of a total solar eclipse have already been described. It sometimes happens that the moon's apparent size is smaller than the apparent size of the sun at the time of eclipse. Our dark companion cannot then cover up the whole of the sun's disc, so a luminous ring is

seen surrounding it. This is known as an "annular" eclipse.

An eclipse of the sun can only be seen where the moon's shadow, the average width of which is about 200 miles, touches the earth. On this account, it is very rarely that a little spot like England lies in the track of the shadow. The last total solar eclipse visible in Great Britain was in 1724, and the next will not occur until 1927. The duration of a total eclipse cannot exceed more than

FIG. 25.—Annular eclipse of the sun as photographed on April 21, 1921, by Dr. W. J. S. Lockyer at Rhiconich, Sutherlandshire, and the partial eclipse photographed at the Royal Observatory, Greenwich.

about seven minutes, and usually totality lasts only two or three minutes.

A total eclipse of the moon is always visible over more than half the earth, and has a duration of a couple of hours. The phenomena observed are not very striking. During totality, that is, when the moon is entirely immersed in the earth's shadow, our satellite can be seen as a dull reddish-coloured disc. The earth is between it and the sun, so no direct sunlight can reach the lunar surface. It may seem, therefore, that the moon is not a cold, dead world, but a globe at a dull-red heat; but this is not the case. The appearance is caused by the action of the earth's atmosphere in diverting the sun's beams from their course. Rays of light from the sun strike our atmosphere, and are bent towards the earth's conical shadow; they fall upon the moon in the shadow, and make its surface visible. In

traversing the earth's atmosphere, and being reflected through it again from the lunar surface, sunlight is deprived of its blue rays, as it is at sunset, and what survives the journey is reddish light only.

By the exercise of a little imagination, some of the grey markings visible upon the lunar surface are seen to bear a resemblance to a human face; and everyone has noticed that the same face is always visible. Sometimes we see a little more of one side or another, but the difference is scarcely noticeable, and the "man in the moon" seems to keep his eyes fixed upon the world from which he was torn. The moon, in fact, always presents the same side towards the earth, and from this it would seem that it does not rotate or spin like the earth. It really does rotate, however, but very slowly, just making a complete turn in the $27\frac{1}{3}$ days required to perform a revolution; that is to say, the moon's rotation and revolution periods are of the same length.

Some people find it difficult to believe that the moon rotates, as the other side is never seen. A simple experiment will illustrate the movement and dispel any possible doubt. Place a globe or a ball of some kind upon a table to represent the earth, and near the wall of the room let a lighted lamp stand for the sun. Now walk round the table, keeping your face to the globe upon it, in the manner that the moon revolves round the earth. When on one side of the table you will face the lamp; when on the opposite side your back will be towards it. For this to occur, you must have turned half round in walking half the distance round the table. Make the other half of the journey, and you will again face the sun, having performed a rotation as well as a revolution.

Sometimes we are able to see over the moon's north pole, and at other times a little beyond the south pole. Also twice a month we are able to see slightly round the moon's east and west edges. Moreover, rotation of the earth causes us to see our satellite from different points of

view. When the moon is rising, we look slightly over one edge, and at the time of setting we peer slightly over the opposite edge. These oscillations of the circle of illumination on the lunar surface are termed " librations." On account of their existence, fifty-nine per cent of the moon's surface is visible at one time or another. The remaining forty-one per cent is never seen by us, though it is illuminated by the sun like other parts of the surface. Nothing is known about the unseen part of the moon and it may be entirely different in structure from the part turned towards the earth.

Galileo, in giving an account of the celestial wonders which had been revealed to him by means of the telescope, refers first to the surface of the moon. Even in his small telescope our satellite appeared a beautiful object; and he observed numerous markings never before seen by man. The words in which the father of physical astronomy states his first observations are full of interest. Galileo's " Sidereal Messenger: Unfolding Great and Marvellous Sights, and Proposing them to the Attention of Every One, but especially Philosophers and Astronomers," was published in 1610. The following extract is from Mr. Carlos's translation :—

" On the fourth or fifth day after new moon, when the moon presents itself to us with bright horns, the boundary which divides the part in shadow from the enlightened part does not extend continuously in an ellipse, as would happen in the case of a perfectly spherical body, but is marked out by an irregular, uneven, and very wavy line, for several bright excrescences, as they may be called, extend beyond the boundary of light and shadow into the dark part, and on the other hand pieces of shadow encroach upon the light; nay, even a great quantity of small blackish spots, altogether separated from the dark part, sprinkle everywhere almost the whole space which is at the time flooded with the sun's light, with the exception of that part alone which is occupied by the great and ancient spots.

"I have noticed that the small spots just mentioned have this common characteristic always, and in every case that they have the dark part towards the sun's position, and on the side away from the sun they have brighter boundaries, as if they were crowned with shining summits. Now we have an appearance quite similar on the earth about sunrise when we behold the valleys, not yet flooded with light, but the mountains surrounding them on the side opposite to the sun already ablaze with the splendour of his beams; and just as the shadows in the hollows of the earth diminish in size as the sun rises higher, so also these spots on the moon lose their blackness as their illuminated part grows larger and larger.

"Again, not only are the boundaries of light and shadow in the moon seen to be uneven and sinuous, but, and this produces still greater astonishment, there appear very many bright points within the darkened portion of the moon, altogether divided and broken off from the illuminated crust, and separated from it by no inconsiderable interval, which, after a little while, gradually increase in size and brightness, and after an hour or two become joined on to the rest of the bright portion, now become somewhat larger, but, in the meantime, others, one here and another there, shooting up as if growing, are lighted up within the shaded portion, increase in size, and at last are linked on to the same luminous surface, now still more extended. Now is it not the case on the earth before sunrise, that while the level plain is still in shadow, the peaks of the most lofty mountains are illuminated by the sun's rays? After a while does not the light spread further, while the middle and larger parts of those mountains are becoming illuminated; and, at length, when the sun has risen, do not the illuminated parts of the plains and hills join together? The grandeur, however, of such prominences and depressions in the moon seem to surpass both in magnitude and extent the ruggedness of the earth's surface."

The description accurately represents and explains what is seen when the moon is viewed through a small telescope at the present time. Galileo, and other observers following him, looked upon the moon as another earth, of which " the brighter portion may very fitly represent the surface of the land, and the darker the expanse of water." Though this idea is now known to be erroneous, the large dark patches retain the name of " seas."

The optical instruments now at the disposal of astronomers enable lunar formations to be studied in detail, and to obtain striking photographs of them. For example, with a large telescope such as that at the Yerkes Observatory, Chicago, which has a lens forty inches in diameter, the moon can be magnified to such an extent that it is brought, optically, to within a distance of about 60 miles from the observer's eye. That is to say, the moon though actually at a distance of about 240,000 miles, can be seen as if it were only 60 miles from the unaided eye ; and every object upon it about 600 feet square becomes distinctly visible.

Many remarkable photographs have been taken of our satellite in recent years, and they are capable of affording valuable information regarding its surface, while their multiplication at different epochs will enable astronomers readily to detect changes of a comparatively minute character in lunar formations.

The features of the lunar surface are conveniently grouped into five classes. There are craters which more or less resemble in appearance the craters of terrestrial volcanoes ; the plains, covering about one half of the moon's visible surface ; the mountain formations, analogous in some respects to the mountain ranges of the earth ; rills or clefts which frequently run like deep trenches through plains and mountains for many miles, and bright streaks which radiate from some of the craters and are unlike anything on the earth.

The word " crater " is used to designate the circular cups

or cavities with which the moon's surface is pitted. They

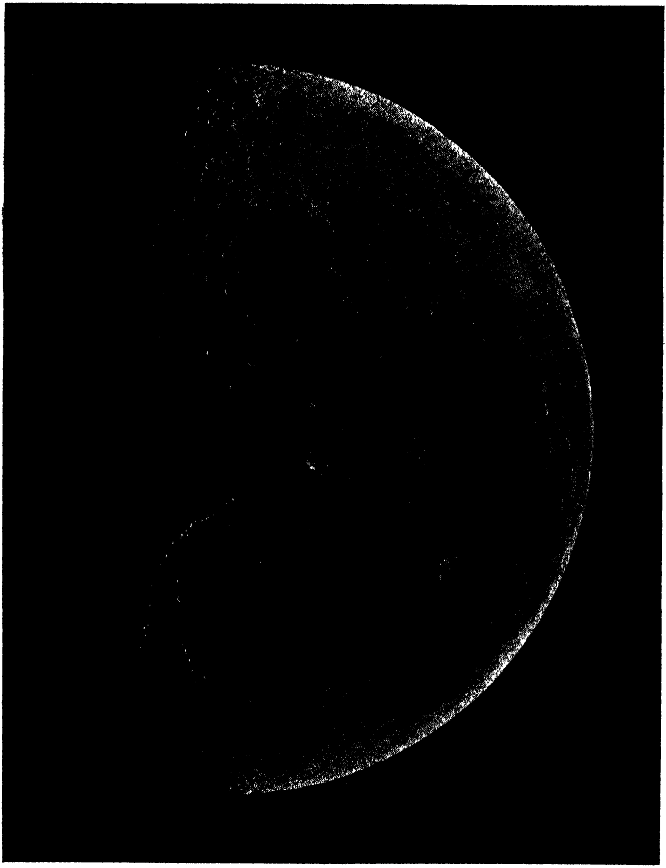


FIG. 26.—Photograph of the moon obtained at the Paris Observatory on September 12, 1903, by Dr. P. H. Puiseux.

vary considerably in size, a few being as much as 100 miles in diameter, while others are so small that they can

only just be seen under the best conditions. A family likeness runs throughout all these craters. Each consists of a rampart or ring, rising sometimes to a height of three or four miles above the surrounding surface. Near the

FIG 27.—The lunar crater Copernicus, fifty miles in diameter, photographed with the 100-inch Hooker telescope of the Mount Wilson Observatory, Pasadena, on September 15, 1919, by Mr. F. G. Pease.

centre of the areas embraced by these circular walls, one or more conical peaks usually occur. In some craters, the peaks rise high above the inside level, known as the crater-floor; others are lower; only traces of central

cones are seen in many craters, and there are craters having no conical peaks at their centres.

Though lunar craters bear a general resemblance to the mouths of terrestrial volcanoes, there is one material

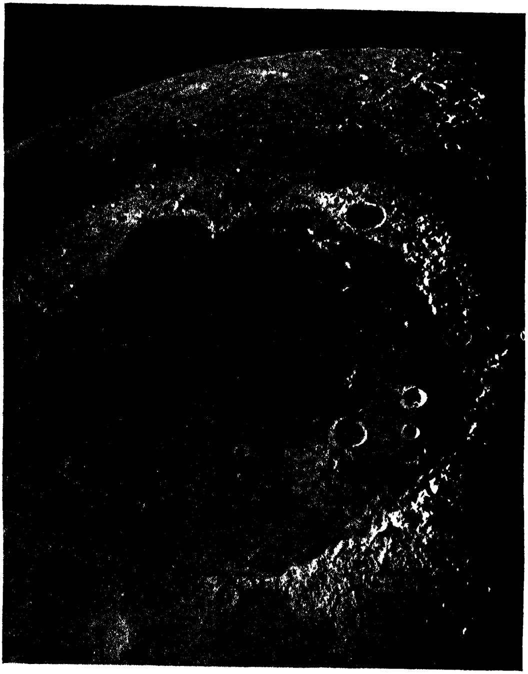


FIG. 28.—Northern portions of the moon, photographed with the 100-inch Hooker telescope of the Mount Wilson Observatory, on September 15, 1919, by Mr. F. G. Pease. The lower range is that of the lunar Apennines.

difference between them. The floors of craters of volcanoes on the earth are generally above the level of the neighbouring country, while on the moon they are depressed below the level of the outside surface, the distance from the top of the rampart to the plateau within being frequently

twice as great as that from the top to the bottom on the outside.

As already mentioned, the mountain ranges are to a certain extent similar to terrestrial ranges, although the more prominent examples are unparalleled on the earth. The grandest of these lunar ranges is undoubtedly the "Apennines," which extends for a length of 450 miles and includes about 3,000 peaks, one of which rises up to a height of nearly 20,000 feet above the surrounding plain. In addition to the ranges there are numerous isolated hills and mountains scattered over the face of the moon.

The rills or clefts are curious formations without any terrestrial analogy. Perhaps the nearest resemblance to the larger rills would be found in the great cañon of Colorado, though even this is not altogether similar. They appear to be great cracks or chasms varying from a few miles up to two or three hundred miles in length, and in breadth up to about two miles.

The systems of bright streaks or rays are the most prominent features of the lunar landscape at the time of full moon, though at other times they become practically invisible. They are found to radiate out from certain craters like spokes from the hub of a wheel, and extend for great distances, apparently surmounting all obstacles such as craters and mountains indiscriminately. The crater named Tycho in the southern hemisphere of the moon forms the centre of the largest of these systems of rays, and the fine crater, Copernicus, is also the centre of radiation of a very prominent system. The nature and origin of these bright rays is still a matter of speculation, and they form one of the most puzzling features of lunar topography. It has been suggested that they consist of fine volcanic dust ejected during an eruption of the crater from which they radiate.

The origin of lunar craters is still obscure. Analogy suggests that the forces which cause volcanic eruptions on the earth have been at work on the moon, and when it is

remembered that the force of gravity on our satellite is only one-sixth that on the earth, it can be understood that the ejected rock would be carried to a much greater distance from the vent than is the case with terrestrial volcanoes. Mr. James Nasmyth, who gave particular attention to the moon, made some interesting suggestions as to the mode of formation of lunar craters and walled plains. A lunar volcano in full activity could eject materials with such a force that they would reach the surface at a distance of several miles from the pipe, and pile up a large rim round it. In the case of a volcano in feeble activity, the ejected rock would not be carried so far, so a rim of small diameter would be built up. As the volcanic action died out, fragments of rock would be so feebly ejected that they would fall round the vent and build up the central cone which characterizes a normal lunar crater. Lava, or molten rock, might then pour out and more or less submerge the cone. Indeed, it is possible that the flow would continue until the central cones were overtopped and the molten rock reached nearly to the rim of the crater. All these stages are represented by actual lunar formations. There are, however, objections to this simple explanation, the chief being that there is no evidence of water on the moon.

If volcanic action were responsible for these lunar formations, it is quite certain that it must now be almost extinct, since very few changes on the lunar surface have been observed which would indicate the presence of powerful volcanic forces. Slight changes have been suspected, the most definite one being probably the case of a small crater named Linne, which is now almost obscured; but in most cases the interpretation, and often the facts themselves, are open to considerable doubt. Certain variations do undoubtedly occur during the course of each month, and have been observed by Prof. W. H. Pickering and others, but they are not volcanic. They occur with fair regularity, depending on the altitude of

the sun at the lunar district observed, and have the appearance of vaporous clouds obscuring the finer detail beneath, or of changes in colour or size of various spots on the lunar surface. These might possibly be optical effects due to the varying angle of illumination of irregular formations, though Prof. Pickering suggests the possibility of their origin lying in the growth of some kind of vegetation under the warming influence of the sun's rays.

Some astronomers and geologists favour the view that the craters were produced by the bombardment of masses of rock when the moon was in a plastic condition.

That the moon has practically no atmosphere is evidenced by several phenomena. In the first place the edge of our satellite is as bright and sharp as other parts of the disc, whereas if an atmosphere existed, it would be dim and hazy; and secondly, the shadows on the moon are always seen perfectly defined and black. Further, when the moon comes between us and a star, the latter disappears instantly behind the sharp edge, and does not become slowly obscured as it would do if a lunar atmosphere came in front of it before the solid surface of the moon.

The temperature of the moon's surface must vary between very considerable limits. For about a fortnight the sun's beams beat upon the land and are untempered by any atmosphere. There is no vaporous blanket to soften the light and heat, or to prevent its loss from the lunar surface. As a result, it is found that the sunlit surface loses its heat so rapidly that it is never above the temperature of freezing water. For about fourteen days the sun never shines on one side of the moon, and then the temperature must fall to a degree compared with which our polar regions would be warm. Mr. Nasmyth remarked in an eloquent passage in his volume on the moon, "Among the consequences of the alternations of temperature to which the moon's crust is thus exposed are doubtless more or less considerable expansions and contractions of the surface material, and we may conceive

that a cracking and crumbling of the more brittle constituents would ensue, together with a grating of contiguous but disconnected masses, and an occasional dislocation of them. We refer again to these phenomena to remark that, if an atmospheric medium existed they would be attended with noisy manifestations. These are abundant causes for grating and crackling sounds, and such are the only source of noise upon the moon, where there is no life to raise a hum, no wind to murmur, no ocean to brim or foam, and no brook to splash. Yet even these crust cracking commotions, though they might be felt by the vibrations of the ground, would not manifest themselves audibly, for without air there can be no communication between the grating or cracking body and the nerves of hearing. Dead silence reigns on the moon; a thousand cannons might be fired and a thousand drums beaten upon that airless world, but no sound would come from them: lips might quiver and tongues essay to speak, but no action of theirs could break the utter silence of the lunar scene."

CHAPTER VI

THE SUN'S FAMILY OF PLANETS

THE planets are the earth's brothers and sisters, and the sun rules over all with gravitational authority derived from its overpowering mass. The path of a planet may be regarded as determined by two tendencies—one that of the planet to move in a straight line and the other the tendency to fall towards the sun. The curve actually followed is a compromise between these two forces. If we imagine that the sun could be annihilated at any instant each member of our little family group would move through space in a straight line until it came under the control of another massive body.

The nearest planet to the sun is Mercury, " the swift messenger of the gods," and remarkable for the vivacity of his motions. Then comes the bright and beautiful Venus. The earth follows. At a still greater distance Mars, " ruddy and awful," runs his race. Beyond it Jupiter makes its stately march. Next Saturn moves, while " his steadfast shade sleeps on his luminous ring." Uranus, the father of Saturn, has a path suitable to its dignity, and last of all comes Neptune at the extremity of our system.

The earth is approximately eight thousand miles in diameter. Let us represent this by one foot and construct an imaginary solar system on the scale of one foot to eight thousand miles. The dome of St. Paul's Cathedral, more than one hundred feet in diameter, is a fitting representation of a hemisphere of the sun. Mercury would be proportionally represented by a baby's head at Chancery Lane; Venus, by a globe rather less than one foot in

diameter revolving in a path at the distance of Charing Cross from the cathedral dome; the earth by a one-foot globe situated at Buckingham Palace; and the moon a cricket ball circling round her at a distance of thirty feet. Mars, a man's head, travelling in a circle having for its radius the distance from St. Paul's to South Kensington Museum; the minor planets or asteroids, small shot, revolving at the distance of Hammersmith; the radius of Jupiter's orbit would be just beyond Richmond, the planet itself being a globe eleven feet in diameter; Saturn, a nine-foot globe would be at Staines, near Windsor, and would move round St. Paul's at this distance; Uranus would be a four-foot globe at Reading; and Neptune, a globe four and a half feet in diameter, would have for the radius of his orbit the distance from London to Oxford. This is an accurate plan of the orbits of the planets and the sizes of the bodies themselves. On the scale adopted, namely, one foot to eight thousand miles, the nearest star has a distance of 500,000 miles.

Sir John Herschel, in his "Outlines of Astronomy," gives the following illustration of the relative magnitudes, distance, and velocities of the planets. "Choose any well-levelled field or bowling-green. On it place a globe, two feet in diameter, this will represent the sun; Mercury will be represented by a grain of mustard seed, on the circumference of a circle 164 feet in diameter for its orbit; Venus a pea, on a circle of 284 feet in diameter; the earth also a pea, on a circle of 430 feet; Mars a rather large pin's head, on a circle of 654 feet; the asteroids, grains of sand, in orbits of from 1,000 to 1,200 feet; Jupiter a moderate-sized orange, in a circle nearly half a mile across; Saturn a small orange, on a circle of four-fifths of a mile; Uranus a full-sized cherry, or small plum, upon the circumference of a circle more than a mile and a half; and Neptune a good-sized plum, on a circle about two miles and a half in diameter. As to getting correct notions on this subject by drawing circles on paper or, still worse, from those very childish toys

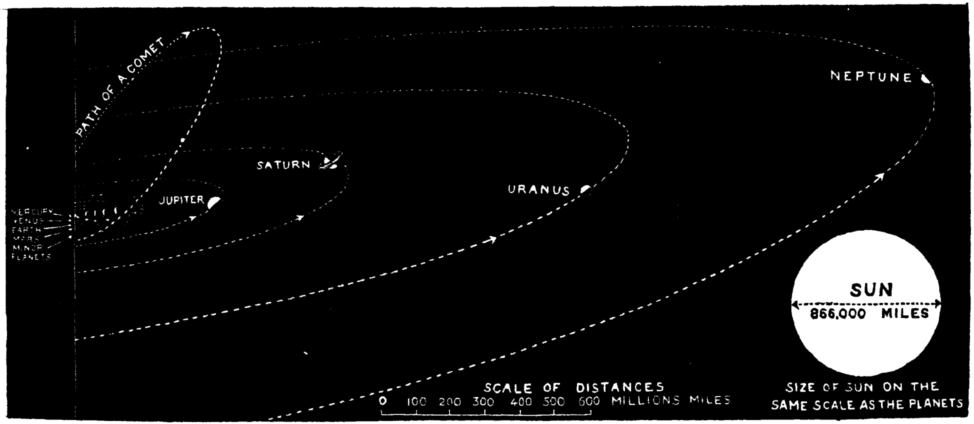


FIG. 29.—Relative distances of the planets from the sun.

called orreries, it is out of the question. To imitate the notions of the planets in the above-mentioned orbits, Mercury must describe its own diameter in 41 seconds; Venus in 4 minutes 14 seconds; the earth in 7 minutes; Mars in 4 minutes 48 seconds; Jupiter in 2 hours 56 minutes; Saturn in 3 hours 13 minutes; Uranus in 2 hours 16 minutes; and Neptune in 3 hours 30 minutes."

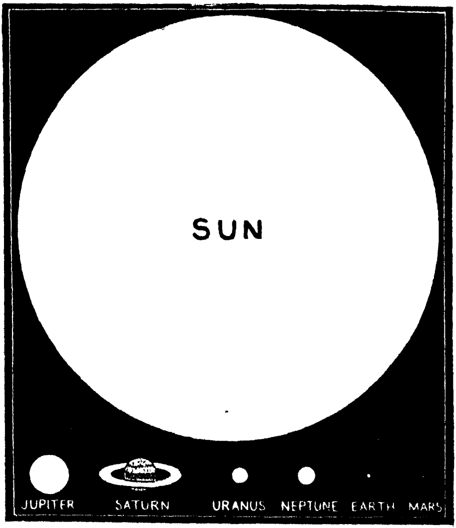


FIG. 30.—Relative sizes of the sun and planets.

The comparative diameters of the sun and planets are shown in Fig. 30.

The so-called weight of the earth is 6,000 millions of millions of millions of tons. If we represent this inconceivable quantity by a weight of one pound, the mass of the sun would be 150 tons; of Jupiter, 310 pounds; of Saturn, 93 pounds; of Neptune, 17 pounds; of Uranus, 14 pounds; of Venus, 13 ounces; of Mars, 1½ ounces; of

Mercury, 1 ounce; and of the moon, rather more than 3 drams. It will be seen from this that the sun considerably outweighs the planets; in fact, its mass is 750 times greater than all the planets put together.

A planet's size and its mass determine the intensity of gravitational attraction at its surface. On this account, the

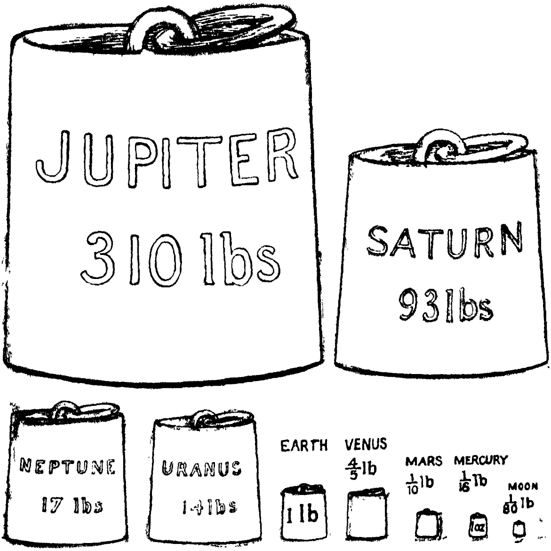


FIG. 31.—Relative masses of the planets and the moon.

same body, if weighed in a spring balance, would appear to have different weights on different planets. A man weighing 12 stone on the earth would weigh 2 tons on the sun, 28 stone on Jupiter, 14 stone on Saturn, 10 stone on Venus, Neptune, and Uranus, 5 on Mercury and Mars, 2 on the moon, and a few ounces on an average asteroid.

The mean density of a planet signifies the density taken as a whole. Thus, the rocks on the earth's surface are, on the average, about two and half times heavier than equal

bulks of water; they increase in density right down to the earth's centre, where the materials must weigh nine or ten times more than equal bulks of water, and the average from the surface to the centre is five and a half. Mercury, Venus and the Earth have all an average density about five times greater than the density of water, or one-half that of lead. The mean density of Venus may be compared to that of a lodestone, of Mars to ruby, of the moon to flint-glass, of Jupiter and the sun to anthracite coal; Uranus has about the density of amber, Neptune of box-wood, and Saturn of walnut-wood.

The planets have many common characteristics. They all travel round the sun in nearly the same plane, and if we could view our system from the pole-star, the direction of motion would be seen to be opposite to that in which the hands of a clock move. Each planet rotates as it moves along its orbit, the direction of spin being the same as that of the onward motion; and the majority of the satellites also revolve in this direction. Just as the different members of a family possess peculiarities of character and features, so do the individual planets.

Mercury is a "will-o'-the-wisp" planet. It moves at the average rate of nearly thirty miles per second, that is, about eighteen hundred times faster than an express train. The planet can be seen only shortly before sunrise or after sunset, and in our latitudes it is generally lost in the mists of the horizon. Near the equator, however, it is quite a conspicuous object, though always near the sun.

Viewed telescopically, Mercury is found to pass through phases like the moon. It also occasionally comes between the earth and the sun, and is then seen as a small black spot crossing the solar disc.

Owing to the proximity of Mercury to the sun, the light and heat received on a unit of surface is much greater than on the earth, and it varies considerably throughout the year of eighty-eight days. The sun is three million miles farther from the earth in the northern summer than in winter. But

this is only a small fraction of the total distance, and the variation of the sun's light and heat due to this cause is scarcely observable. The path of Mercury is much less circular than that of the earth; indeed, it is so strongly elliptical that in one part of the orbit the planet is fourteen million miles nearer the sun than when at the opposite point. On this account, the intensity of solar radiation on the planet must change enormously during a revolution. If Mercury has a dense atmosphere, the blaze of sunlight must be softened in traversing it, as it is with us, but the evidence so far obtained indicates that the envelope is not so dense as that which surrounds the earth.

No conspicuous markings are visible upon the surface of Mercury, so the character of the planet cannot be read with any degree of certainty. By observing the movements of spots upon the face of a planet, the time of rotation is obtained, as in the case of the sun. The indistinctness of the markings on Mercury renders the determination of its rotation period difficult. Until 1889, it was generally supposed that this period was about twenty-four hours, but a well-known Italian observer, Schiaparelli, then announced that Mercury has always the same hemisphere turned towards the sun, like the moon to the earth, in which case both rotation and revolution are accomplished in eighty-eight days.

The late Prof. Lowell claimed to have been rather more successful in his observations of Mercury, and was able to distinguish some very dark lines, narrow and irregular in character, on the surface of the planet. From his observations he deduced a rotation period of eighty-eight days, which is now regarded as the most probable value. He was unable to trace any evidence of an atmosphere on Mercury and attributed the dark lines mentioned above to cracks, which they resembled very closely in appearance. This seems not to be altogether unlikely, since the rays of the sun—probably directed always on to the same hemisphere—must be of very great intensity, especially if

untempered by an atmosphere, and might be expected to produce considerable effects on the surface of the planet.

That beautiful gem of the sky—the planet Venus—has attracted the attention of all. When visible near Christmas time, this peerless planet has been regarded as the "Star of Bethlehem" by many people, though there is no reason to believe that it was the object seen by the wise men of the East.

Like Mercury and the moon, Venus is seen differently illuminated at different times, according as we view the bright surface from different aspects.

There is an old proverb which says, "Never prophesy until you know." In science it is often possible to obtain sufficient knowledge to enable a prediction to be made with confidence that it will come true. As the result of studies of the movements of the planets, a Polish monk, Nicolai Copernicus, who lived in the years A.D. 1473–1543, showed in a great work that they all move around the sun at different distances. In his time, it was believed that the earth is fixed, while the sun and other celestial bodies travel round it; but he held that the earth is a planet and that between it and the sun are the two planets Mercury and Venus, the latter of which is often seen shining brightly as a "morning" or an "evening" star. Copernicus knew that if this really represents the arrangement of bodies in the sun's family of planets, Mercury and Venus should go through the same kind of changes as the moon does, that is to say, they should sometimes be crescent-shaped, and at other times have "half-moon" and "full-moon" appearances. There were no telescopes in his day, but he was so convinced of the truth of the doctrine he described that he predicted these phases of Mercury and Venus, though they had never been seen. Not until more than sixty years after his death was a telescope used to observe the planets, but it was then found that Mercury and Venus did actually pass through the phases or changes anticipated by Copernicus.

Galileo was the first observer of these changes, and he notified the discovery in an anagram to Kepler, which read,

"*Haec immatura a me jam frustra leguntur.*"

These letters, when reduced to their proper order, form the sentence,

"*Cynthiæ figuras æmulatur mater amorum.*"

"*The mother of the Loves rivals the phases of Cynthia.*"

That is,

"*Venus imitates the phases of the moon.*"

The letter in which Galileo gives Kepler an account of his observations is of particular interest. "You must know," wrote the originator of physical astronomy, "that about three months ago, when the star of Venus could be seen, I began to look at it through a telescope with great attention, so that I might grasp with my physical senses an idea which I was entertaining as certain. At first, then, you must know the planet Venus appeared of a perfectly circular form, accurately so, and bounded by a distinct edge, but very small; this figure Venus kept until it began to approach its greatest distance from the sun, and, meanwhile, the apparent size of its orb kept on increasing.

"From that time it began to lose its roundness on the eastern side, which was turned away from the sun, and in a few days it contracted its visible portion into an exact semicircle; that figure lasted without the smallest alteration until it began to turn towards the sun, when it leaves the tangent drawn to its epicycle. At this time it loses the semicircular form more and more, and keeps on diminishing that figure until its conjunction, when it will wane to a very thin crescent.

"After completing its passage past the sun it will appear to us, at its appearance as a morning star, as only sickle-shaped, turning a very thin crescent away from the sun; afterwards the crescent will fill up more and more until the planet reaches its greatest distance from the sun, in which position it will appear semicircular, and that

figure will last for many days without appreciable variation. Then by degrees, from being semicircular it will change to a full orb, and will keep that perfectly circular figure for several months ; but at this instant the diameter of the orb of Venus is about five times as large as that which it showed at its first appearance as an evening star."

" From the observation of these wonderful phenomena we are supplied with a determination most conclusive, an appealing to the evidence of our senses, of two very important problems, which up to this day were discussed by the greatest intellects with different conclusions. One is that the planets are bodies not self-luminous (if we may entertain the same views about Mercury as we do about Venus). The second is that we are absolutely compelled to say that Venus (and Mercury also) revolve round the sun, as do also all the rest of the planets. A truth believed, indeed, by the Pythagorean school, by Copernicus, and by Kepler, but never proved by the evidence of our senses, as it is now proved in the case of Venus and Mercury."

It follows from these facts that Venus must sometimes come between the earth and the sun, and like Mercury be seen projected upon the solar disc as a dark spot. These " transits of Venus " have been observed, and are important because they furnish a means of determining the distance of the sun from the earth.

Venus is so gloriously bright that the markings on her face can scarcely be distinguished. White patches have been seen by some observers round what are supposed to be the planet's poles, and it is possible that they are regions of ice and snow such as exist round the earth's poles. A number of dusky markings have also been detected.

The rotation period is still undecided. Until 1889 it was said to be about twenty-four hours, but Schiaparelli then questioned the observations which assigned this time of spin to the planet. His scrutiny of the features of Venus led to the conclusion that the rotation takes place in 225 days, this being also the period of revolution round the

sun. According to this, portions of the surface of Venus (and Mercury also) are never exposed to sunlight. Later observations by Prof. Lowell have tended to confirm this hypothesis, but the markings on Venus are very faint, and it is scarcely safe to place implicit reliance on observations of this class alone.

The method by which the spectroscope may be employed to discover the motion of a luminous body in the line of sight has already been described in chapter 4. It will easily be understood that if we could examine spectroscopically the apparent disc of Venus, one half of the disc would be found to be approaching us and the other half to be receding from us on account of the planet's rotation. The actual velocity of approach or recession could be measured with the help of the spectroscope, and hence the period of rotation could be deduced. Several observers have applied this method to the problem, with varying success and rather discordant results. Belopolsky in 1900 decided in favour of the short-period rotation of about twenty-four hours, but a few years later Prof. Lowell and Dr. Slipher obtained results of a negative character. They were unable to detect any rotation at all, though the accuracy of the method was such that the comparatively large velocity implied by a short-period rotation should easily have been detected. A long-period rotation, therefore, appeared to be suggested.

A third hypothesis has recently been put forward by Prof. W. H. Pickering, based on his visual observations of the planet. He claims that Venus rotates in a period of 68 hours, in such a manner that the axis of rotation lies very nearly in the plane of the orbit. Such a state of affairs is not incompatible with the spectroscopic observations referred to above, but definite confirmation is naturally required. More extensive observations with the spectroscope should quickly confirm or disprove this theory.

There is no doubt that Venus has an atmosphere. The thin ring of light seen round the planet, just previous to a

transit, is clear evidence of its existence. The atmosphere is probably twice as dense as our own; but recent observations with the spectroscope indicate that both water-vapour and oxygen are absent from it.

When a superior planet, that is, a planet with its orbit outside the earth's orbit, is on the same side of the sun as the earth, and the bodies are exactly in a line, it is due south at midnight, and is said to be in opposition. Now, planetary orbits are not concentric; if they were, the distance of a planet at an opposition would always be the same. Mars deviates considerably from this uniformity. If opposition occurs when the planet is at its greatest distance from the sun, the span of space between it and the earth amounts to more than sixty millions of miles; if, however, Mars is at its nearest approach when the earth comes between it and the sun, the distance from us to our ruddy brother may only be thirty-five million miles. When the latter conditions are approached the opposition is favourable, for astronomers have then the best opportunity of studying the planet.

Venus can be nearer to the earth than any other planet, but, as has been remarked, the markings are very faint and indistinct, owing to the dense atmosphere which enshrouds it. Mars is the next planet which approaches us within a reasonable distance, and it does so without the disadvantages which accrue to an inferior planet like Mercury or Venus. The result is that the features of the God of War have been delineated over and over again. The "scars and patches" on the face of Mars are of three kinds. Areas of a reddish shade predominate and are supposed to represent land surfaces, while regions of a greenish tinge were at first considered to be seas. It has recently been proved, however, that the latter regions cannot be stretches of water; and they are believed to represent vegetation of some kind. Round the Martian poles are white patches or ice-caps similar to those covering the polar regions of the earth. It is believed these really

represent masses of snow and ice; and for this reason. When it is summer in the northern hemisphere of Mars, the northern ice-cap contracts, owing doubtless to the melting of the ice; and at the same time, the ice-covered region in the southern hemisphere increases in extent. Conversely, during the southern summer, the southern ice-cap diminishes and the northern one increases in size.

Markings of a temporary character sometimes obscure

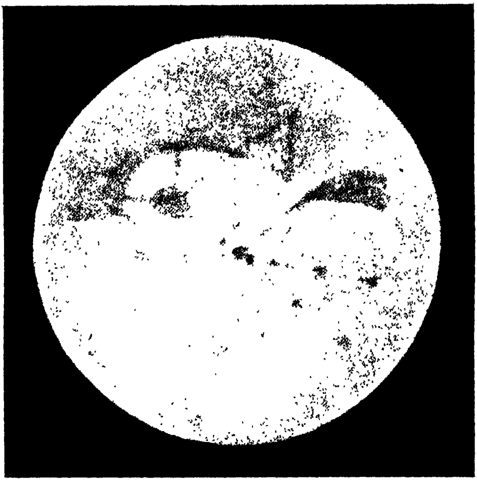


FIG. 32.—Drawing of Mars by Prof. P. Lowell, showing "canals" and oases.

parts of the planet's disc, and are regarded as clouds. The atmosphere, however, cannot be anything like as dense as the earth's. In 1877, Schiaparelli, one of the most acute of observers, detected a number of straight streaks crossing the land surface of Mars in all directions, and sometimes for thousands of miles. The streaks have received the unfortunate name of "canals," and this, of course, suggests that they were formed artificially:

"channels" is a much more appropriate name. Later the astronomical world was again startled by Schiaparelli announcing that he had seen some of the channels double. More than one observer has denied the existence of such markings as those mapped by the Milan astronomer. But on the whole, the visual and photographic observations made during other favourable oppositions go to confirm Schaparelli's work.

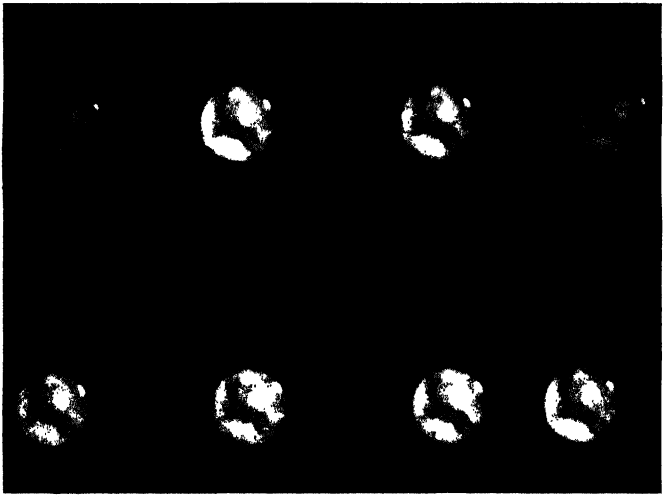


FIG. 33.—Photographs of Mars obtained on September 28, 1909, by Prof. E. E. Barnard.

The greatest advances since the time of Schiaparelli in our knowledge of Mars have undoubtedly been made by the late Prof. Lowell, who spent the greater part of his life in studying and mapping the surface markings of this planet. He possessed the advantages of having an excellent telescope, situated in a position of exceptionally clear atmosphere (which is of the greatest importance for such observations); and with an eyesight specially trained by

long practice in this kind of work, he was enabled to discover many details of great interest. The existence of the channels seen by Schiaparelli was confirmed, together with the doubling effect sometimes seen; and many more channels and other markings were added to the maps of the Italian pioneer. The theory originally proposed that the dark grey patches were Martian seas, was disproved by the fact that Lowell discovered several channels crossing them in different directions, which would be obviously impossible if they were of an aqueous nature. Prof. Lowell also attempted to photograph the planet Mars, and was able to obtain results sufficiently good to show that the channels were not optical illusions—as had been suggested by many—and to confirm many of the observations which he had made visually.

As the markings on Mars are permanent and definite, the period of rotation can be accurately determined. It is found to be 24 hours, 37 minutes, 22 seconds. The Martian day is thus only slightly longer than our own. There is reason to believe also that the seasons on Mars are probably very similar to those of the earth.

Mars has two satellites, first mentioned by Dean Swift, in "Gulliver's Travels," published in 1726. When describing the works of the astronomers on the island of Laputa, Gulliver is made to say, "They have likewise discovered two lesser stars or satellites, which revolve round Mars, whereof the innermost is distant from the centre of the primary planet exactly three of its diameters, and the outermost five; the former revolves in the space of ten hours, and the latter in twenty-one and a half." By a remarkable coincidence, Swift not only guessed the number of the satellites correctly, but in causing one to move round the primary in less time than the planet itself rotates, he prophesied what would have been deemed impossible if it were not proven by actual facts. Prof. Asaph Hall discovered the two satellites of Mars in 1877, using the Washington telescope, having an object-glass

twenty-six inches in diameter. They are two of the faintest bodies in our sytem, and can only be seen by acute observers with large telescopes. Phobos and Deimos are the names by which the satellites are known. Phobos is less than four thousand miles from the surface of Mars, and makes more than three revolutions while the planet rotates once; Deimos is about three times farther removed from the surface, and takes thirty hours to perform a revolution.

The distances of the planets from the sun are connected by a simple relation. If we write the series of numbers 0, 3, 6, 12, 24, 48, 96 (every number except the second being double that preceding it), and add 4 to each, the series 4, 7, 10, 16, 28, 52, 100, is obtained. For an unexplained reason this series represents very closely the relative distances of planets from the sun. Taking the distance of the earth as unity, the comparative distances of planets are, Mercury, 0·4; Venus, 0·7; Earth, 1·0; Mars, 1·5; ——, 2·8; Jupiter, 5·2; Saturn, 9·5. This is known as Bode's Law.

When this law was published it was pointed out that the actual series of planetary distances did not exactly correspond to the series arrived at numerically. No planet was known to revolve round the sun between Mars and Jupiter, so the number 28 was not represented in actuality. All the other numbers fit the planetary distances so nicely that astronomers at length concluded that a planet must exist to fill the gap in the series, and it only wanted discovering. A band of observers, therefore, decided to search for the unknown body. But before the work had well begun, on the first night of the nineteenth century, Piazzi, of Palermo, discovered a new planet, and named it Ceres. Further observations enabled the path of the new body to be calculated, and the distance from the sun was found to be very nearly 2·8 times the earth's distance. The vacancy would therefore seem to be filled, though by a body far smaller than any of the other members of our system. A year later another small planet was discovered by Olbers, and named Pallas, its distance being about the

same as that of Ceres. In 1804 and 1807, two more were "picked up" as they strayed along the ecliptic, and named Juno and Vesta. Encke discovered the next in 1845. Since then the list of "minor planets" or "asteroids" has been steadily growing, and the number now known is about a thousand.

Little is known about the asteroids, except that they are very small. The brightest, Vesta, is just visible to the naked eye, and has a diameter of less than three hundred

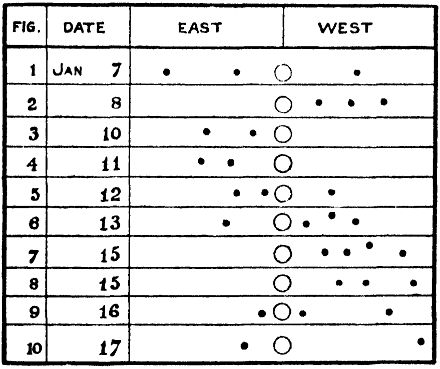


FIG. 34.—Galileo's first observations of the positions of Jupiter's satellites in relation to the planet.

miles, and Ceres and Pallas, though larger, are not so luminous. The rest are extremely small, and quite invisible except in moderate-sized telescopes.

It has been suggested that the asteroids are parts of an exploded planet, but, for reasons into which we cannot here enter, this theory is improbable. Another view is that the bodies represent the materials which would have formed a single planet had it not been "spoiled in the making" by some disturbing influence.

With the exception of the minor planets, the bodies so far described are more or less like the earth; they are

therefore termed "terrestrial" planets. From Jupiter outwards, however, we deal with quite a different class of bodies, all much larger than the terrestrial planets, and all less dense.

On January 7, 1610, Galileo discovered that Jupiter had a retinue of four satellites, which were to him what the moon is to the earth. "In this circumstance" argued he, "we have a notable and splendid argument to remove the scruples of those who can tolerate the revolution of the planets round the sun in the Copernican system, yet are so disturbed by the motion of our moon round the earth, while both accomplish an orbit of a year's length about the sun, that they consider that this theory of the constitution of the universe must be upset as impossible; for now we have not one planet only revolving about another, while both traverse a vast orbit about the sun, but our sense of sight presents to us four satellites circling about Jupiter like the moon about the earth, while the whole system travels over a mighty orbit about the sun in the space of twelve years."

In 1892, nearly 283 years after Galileo's observations, Prof. E. E. Barnard discovered a fifth body revolving round Jupiter at a less distance than the nearest of the other satellites. The instrument, by means of which the discovery was made, was the 36-inch of the Lick Observatory. The fifth satellite is so near to Jupiter that it is almost smothered in the glare from his disc, and is therefore extremely difficult to see. Since the year 1892 several more satellites have been discovered, and the total number at present known to be revolving round Jupiter is nine. The latest discovery was made photographically by Mr. S. B. Nicholson at the Lick Observatory. He found that the new satellite required three years to complete its revolution round Jupiter, and that it exhibited the peculiarity of "retrograde" motion, i.e. it performed its journey in the reverse direction to that of most of the other satellites.

Jupiter is covered with markings, the most conspicuous

of which are dark bands running parallel to the planet's equator, and known as "belts." Other spots and markings of a variety of tint are distributed over the surface, and make the planet a beautiful object in the telescope.

Jupiter rotates once in about ten hours, that is, makes

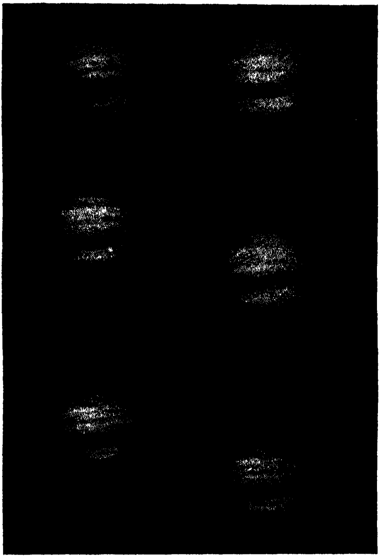


FIG. 35.—Photographs of the planet Jupiter, taken by Mr. J. H. Reynolds with a 28-inch reflector at his observatory at Harborne, Birmingham.

nearly two and a half turns in one of our days. A consequence of this extremely rapid rate of spin is a considerable polar depression. The period is not determined, however, with such exactness as obtains to Mars, the reason being that the spots are not permanent features on a solid surface, but masses of cloud and vapour and breaks in them, many of which rapidly change in character. In 1878, a large "red spot" became conspicuous in

Jupiter's southern hemisphere, and is still just visible on the planet. What the spot exactly is no one can definitely say. Some observers consider that it represents a part of the planet's solid surface seen through a break in the clouds, but the prevailing opinion is that it is a mass of vapour. If the former idea were correct, all the coppery-coloured tints are probably more or less solid surfaces, and the greyish tones may be water, the changes of tint being produced by variations in the Jovian atmosphere. There is no doubt whatever that this atmosphere exists, and contains a large amount of vapour, which is condensed into clouds like those at the earth. Of "mighty rushing winds" there is also clear evidence.

At the distance of Jupiter, solar radiation is twenty-seven times less intense than at the earth's distance. This amount is too small to produce the rapid and frequent changes which are observed in the planet's appearance, hence it is inferred that it possesses a large amount of original heat, though it is not to any appreciable extent incandescent. The low mean density of the planet, and the rapidity with which it rotates, give support to this idea.

As to the physical condition of Jupiter we can only speculate. A small solid nucleus may be surrounded by a very deep atmosphere, or, and this is more likely, a semi-fluid globe may be enveloped in dense clouds and vapour. It is certain that the changes observed are chiefly of an atmospheric character, and that some markings are below others, but whether the surface has been seen or not, is not known; indeed, it is doubtful whether any real surface exists at all.

Proceeding from the sun, Saturn is the next planet encountered. To the naked eye this object at its best appears only like a bright star, but the telescope has revealed a fact which makes it one of the most interesting in the heavens, and by far the most remarkable member of our system. When Galileo first observed Saturn he

thought he could distinguish two small companions almost touching the surface of the planet, and made the announcement, "I have observed the most distant of the planets to have a triple form." As time went on the two attendants became smaller and smaller, and finally disappeared altogether. This perplexed the astronomer considerably, for if he were mistaken on this point, all the observations

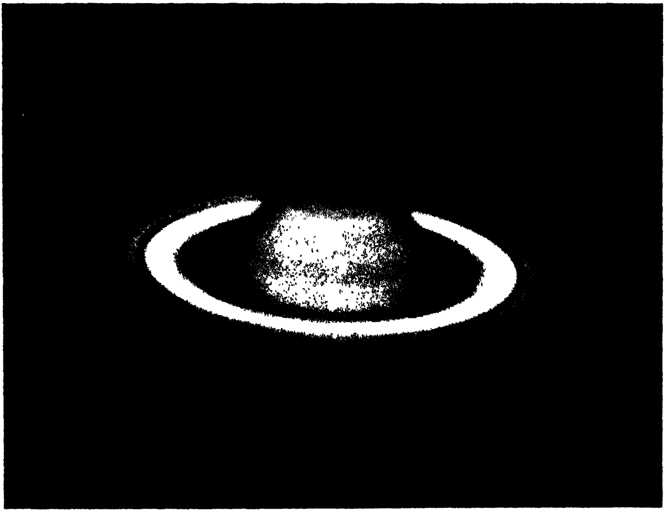


FIG. 36.—Photograph of the planet Saturn taken by Prof. E. E. Barnard with the 60-inch reflector at Mount Wilson Observatory.

he had made would be open to doubt. He pathetically remarked, "I do not know what to say in a case so surprising, so unlooked for, and so novel. The shortness of the time, the unexpected nature of the event, the weakness of my understanding, and the fear of being mistaken, have greatly confounded me."

But Galileo's eyes had not deceived him. After a time what was again supposed to be two small globes were seen

to hold the planet between them. It was not until nearly half a century after Galileo's observation that the true nature of these objects was revealed. Huyghens then showed that Saturn was surrounded by a ring-system. In the words of his announcement, " The planet is surrounded by a slender flat ring everywhere distinct from its surface, and inclined to the ecliptic." Cassini afterwards found that a dark line could be seen round the flat of the ring. This is not merely a marking but a separation between two concentric rings. Two hundred years later, in 1850, Prof. Bond discovered a third ring nearer the planet than the others, and much more difficult to see. This is known as the " crape-ring," a happy term which expresses the fine texture observed.

Saturn travels round the sun with its flat rings inclined about twenty-eight degrees to the plane of the earth's orbit. The result is that we sometimes see the northern side of the ring and sometimes the southern. Once in about fifteen years the plane of the rings passes through the sun, and only the edge facing the sun is then lit up. It was owing to these changes in the amount of illuminated surface visible that Galileo's " globes " disappeared, for they were not globes at all but the rings. Good telescopes then show what looks like two spikes, one on either side of the planet. The spikes are seen to be irregular in thickness, thus showing that the rings are not uniform sheets. To understand the cause of the phases through which the rings pass, place a lamp upon a table, and walk round it while a friend carries round a plate inclined to the level of the table, and always in the same direction. According to the relative positions of yourself and your friend, the plate is sometimes viewed edgeways, sometimes squarely, and sometimes obliquely, just as is the case with Saturn.

The outer ring of Saturn has a diameter of about 170,000 miles, and the average thickness is less than 100 miles. Hence, even if the bright rings were solid concentric sheets of the strongest material with which we are acquainted,

their vast extent and insignificant thickness would make them very flimsy, and comparable to a sheet of writing-paper round a large globe. But solid rings could not exist round a globe of Saturn's dimensions, and a liquid ring would soon be broken up. The only condition in which the rings can exist is that of innumerable particles revolving round the planet like the asteroids round the sun. That this is the true state of affairs was proved spectroscopically by Prof. Keeler. He determined the velocity of rotation of Saturn's rings round the planet with the help of a spectroscope, in a manner similar to that already described with reference to the rotation of Venus. His results showed quite unmistakably that the outermost portions of the rings move more slowly than those portions nearer to the planet, which would be impossible if the rings were solid bodies since in such a case the outer parts would have to move quicker than the inner in order to complete their revolution in the same time. Since the reverse conditions are found to obtain, it is evident that the rings must be composed of parts in independent motion. It can be proved that each member of a swarm of solid particles would be caused to revolve round Saturn in the plane of the equator, just as the rings are observed to do.

Saturn is distinguished in other ways in addition to its marvellous rings. It has the least mean density of any of the planets; indeed, it only weighs as much as a globe of walnut-wood of the same size, and would therefore actually float in water. The polar flattening is greater than any other planet. This follows as a consequence of the low density and the high velocity of rotation (about 10¼ hours). Cloud-belts similar to the belts of Jupiter are seen, and the markings undergo changes, but not in the rapid and turbulent manner observed on Jupiter. Saturn also resembles Jupiter in having a group of attendants; these are ten in number, and the outermost moves in a direction opposite to that of the others.

We have come to the end of the planets known to the

ancients. The date of their discovery is anterior to any times of which there is any historic record. The first planet added to the list was found by Sir William Herschel in 1781. It is just visible to the naked eye at times, but not bright enough to attract any attention. Herschel was "searching the skies" when a strange-looking star attracted his attention, and after watching it for some time under different conditions, he concluded that it was a comet. An announcement of the discovery was made, and other astronomers observed the object. It was soon found, however, that the body did not move in a cometary path, and the conviction was gradually forced upon astronomers that it was a new planet. Such a thing had never been heard of before, for every astronomer had looked upon Mercury and Saturn as representing the Alpha and the Omega of the solar system. The name of Uranus was given to the planet, and when its orbit had been properly calculated, the mean distance from the sun was found to be nineteen times the earth's distance, which agreed very well with the number given by Bode's law.

Very little is definitely known about Uranus. Its mean density is about the same as that of the sun and Jupiter, that is, rather more than the density of water. The physical condition is probably similar to that of Jupiter and Saturn, and there is evidence that the planet possesses inherent or original heat. Owing to the indistinctness of the markings on the planet's surface, the period of rotation has not been obtained. Faint belts have been glimpsed by some observers, and from their direction the position of the equator has been estimated. The poles must, of course, be at right angles to this position. But observations of polar compression locate the poles in quite a different position from that indicated by the cloud-belts. Both cannot be right, and since the markings are excessively faint, it is probable that the direction deduced from measures of the flattening is correct.

Uranus has four satellites revolving round it in nearly circular orbits, and probably in the plane of the equator. The plane of the orbits is inclined about eighty degrees to the ecliptic, hence the satellites are seen almost at right angles to the ecliptic, instead of lying nearly in it, like those of the planets already described. More remarkable still is the fact that the direction in which the satellites move is the reverse of that possessed by all the planets and by most of the satellites to which reference has been made.

Uranus having been assigned a place and name, was expected to conform to the rules of planetary motion. Calculations were made on the assumption that it would do so, and the places it ought to occupy at particular dates were predicted. But observation did not confirm prediction as time went on. Uranus was never to be found in exactly the proper place; it was apparently being misguided by some unknown influence.

In 1845, the deviation from the calculated path had become so great that astronomers all agreed that something must be done to find the body which had Uranus under its control. Science, and especially the science of astronomy, is nothing, if not exact. The amount by which the real place of Uranus differed from the calculated position would be considered by most people as far too small to be worth troubling about. A halfpenny viewed at a distance of fifty feet would cover the difference between the two points. Two astronomers, however, set to work to calculate the position of the supposed disturbing body. One was a young and then unknown Englishman named Adams; the other was a French mathematician, Leverrier. Each worker independently found where the controlling planet ought to be, and each communicated his results to an observer. Adams laboured under the double misfortune of being young and of having no position in the astronomical world. The result was that his calculations were not regarded very seriously. Leverrier finished his

investigation after Adams, and sent to Dr. Galle at Berlin, telling him where to look for the body which had been felt, but not seen. On the very night (September 23, 1846), and in less than half an hour after the search was commenced, the new planet was found close to the predicted place.

This planet is known by the name of Neptune. Unlike the rest of the planets, its distance from the sun does not conform to Bode's law. At 30 times the earth's distance, Neptune journeys round the sun, whereas Bode's series previously mentioned (p. 102) would make the number 38.

Next to Saturn, Neptune is the least dense of the planets. The period of rotation cannot be determined, owing to the absence of visible markings. In all probability the planet possesses inherent heat, and is in a similar vaporous condition to Jupiter, Saturn, and Uranus. One satellite has been found revolving round Neptune, its distance being about the same as that of the moon from the earth. The orbit is inclined considerably to the ecliptic, and in it the satellites move in the same retrograde fashion as the Uranian satellites.

The question of the habitability of the planets and satellites is full of interest, but, unfortunately, we have no evidence upon the subject. It is scarcely possible to conceive of life upon the sun, and certainly not life as we know it. Where iron and other metals are dissipated into vapour as easily as water upon the earth, terrestrial organisms could not exist. A lunar residence does not offer many advantages. Those who long for a quiet life would attain their desire upon our satellite, for, in the absence of an atmosphere no sound could be heard. But the climate is far from being equable, owing to the considerable range of temperature. In his "First Men in the Moon," Mr. H. G. Wells fantastically suggested that the inhabitants of the moon do not live upon the surface, but have burrowed towards the centre where warmer regions prevail; and he

based a brilliant story of conditions of life upon our satellite upon this view. It is, of course, not impossible that a race should be created specially fitted to live upon the moon. To obtain information upon this point, it was proposed some years ago to erect immense triangles or circles upon plains or desert places of the earth. If there are Lunarians, and they possess telescopes, our geometrical figures might be seen and replied to by setting up similar figures upon their own globe. Venus and Mars present conditions more congenial to human life than the sun or moon. The former planet has an atmosphere rather denser than that of the earth, and there is very little difference between the sizes of the two globes. Though the intensity of solar radiations at Venus is about twice that received by the earth, the dense atmosphere would modify it very considerably. Indeed, so far as one can tell, many, if not most, parts of Venus could be inhabited by human beings.

During oppositions of Mars much interest is often taken by the general public in the question as to whether the planet is peopled or not. In many respects Mars is very similar to the earth. Its day is about the same length, and the seasonal differences are alike. We see markings supposed to be water, and others interpreted as land; hence it seems as if the planet is favourable for habitation. On the other hand, though Mars has an atmosphere in which water vapour is present, it is nothing like so dense as that of the earth. An astronomer on Mars would most probably be unable to see any of the features on the surface of the earth, owing to the vaporous envelope which surrounds us, whereas it is only rarely that clouds obscure any portion of the Martian surface. Various projects of signalling to Mars have been suggested, but it is not likely that any of them will be carried into effect for a number of years. If there are Martian people they must watch our earth with great interest, and probably point to it as the abode of love and peace, for it must be a beautiful

object in their sky. When we see Mars at his best, however, the earth is invisible to the Martians. With the exception of Mercury, none of the remaining planets are in a fit condition for life as we know it ; for each very probably consists of dense vapours surrounding a semi-fluid nucleus, and devoid of a crust like that of the earth.

CHAPTER VII

COMETS AND METEORS

THE movements of the sun, moon, and planets, are so regular that people in general pay little attention to them. The sun can be confidently expected to rise to-morrow morning and present its usual appearance; we have faith that the moon will wax and wane in the future as it has done in the past, and that the planets will be found in their appointed places for many years to come. The regularity of these returns was observed long before the laws which govern them were known, and men saw no cause to fear the bodies which conducted themselves so steadily. Comets, on the other hand, have such rapid and apparently erratic motions that they have at all times been regarded with terror. They appear in the sky without harbinger of any kind, "shake their horrid hair" over the earth as they increase in brilliancy and magnitude, and apparently threaten the world with evil. Even among civilized peoples to-day, great comets are viewed with feelings of awe and anxiety. No wonder, then, that in earlier days the appearance of a comet was regarded as a manifestation of divine wrath, and in the object itself heated imaginations saw forms of javelins and swords, dragons and demons, and burning flames.

Many of the six or seven hundred comets recorded in historic time are associated by ancient chroniclers with terrestrial affairs. Shortly after the murder of Julius Cæsar, a comet was seen, which the Romans imagined represented his apotheosis as expressed in Shakespeare's words:

> When beggars die, there are no comets seen;
> The heavens themselves blaze forth the death of princes.

Josephus records that a comet hung over Jerusalem in the year A.D. 66, while the city was being besieged by Titus, and he refers to it as having "the figure of a sword," while "in it," says Pliny, "one may see the image of God in human form." A bright comet seen in 1066 was regarded as a presage of the conquest of England by William of Normandy, and is figured in the Bayeux tapestry. Both these comets are now known to be the same object coming into view at different times.

The discovery of the law of gravitation provided the clue to the movements of comets. Newton had found that the motions of the known members of the solar system were completely accounted for by this universal law of attraction. Some years later his friend, Halley, conjectured that comets were subject to the same law, and he examined the characteristics of a number of cometary orbits with this view in his mind. As a result of the inquiry, Halley showed that a comet of 1682 and one of 1607 were identical, and a relation appeared to exist between them and a comet of 1531. From this he inferred that the three objects were one and the same body travelling round the sun in a period of about seventy-six years. If that were so, the comet should return in 1759, and the astronomer confidently predicted its reappearance though he did not live to see the prophecy fulfilled. Halley's comet made the long-expected call, and by so doing showed that its motions were controlled by the same "secret, strong, attractive force" as that which binds the planets to the sun.

The planets travel in elliptic orbits around the sun. True, the ellipses are of comparatively small eccentricity, that is, they differ only slightly from circles, but Newton found that this kind of orbit followed as a necessary consequence of the law of gravitation. Since the law can

explain one kind of elliptical motion it ought to be applicable to ellipses of any eccentricity, and Halley's work proved that it was so.

A clear idea of the character and properties of an ellipse can be obtained by the simple method of constructing the figure shown in Fig. 37. When the two pins are close together, the figure traced out by the pencil held in the loop of the thread is scarcely distinguishable from a circle. By increasing the distance between the pins, ellipses of a

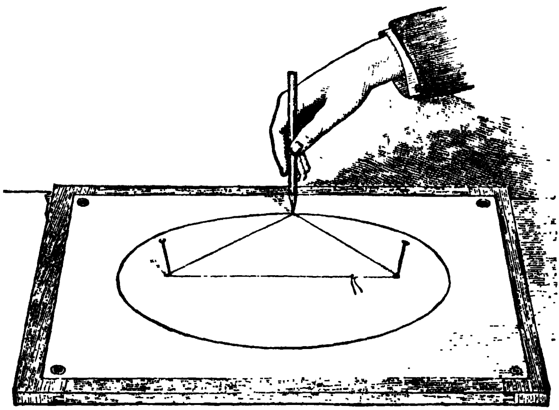


FIG. 37.—Simple method of drawing an ellipse. The two pins are at the foci of the ellipse.

more and more elongated form are produced, and if it were possible to place one of the pins at an infinite distance from the other, the beautiful geometrical figure known as a parabola could be drawn. Hence, there is every gradation between an ellipse in which the two foci very nearly coincide, and a parabola in which the foci are separated by an infinite distance.

We know that a body moving in an elliptical path traverses the track over and over again. A body moving in a parabolic orbit round the sun must behave very differently. It comes from outer space, swings round the

sun in the focus of the curve, and then goes off never to return, for it can never get round the other focus. The apparently adventitious motions of comets are thus reducible to law and order, and the decline of the superstitious dread in which the objects had been held began with this discovery.

Two hundred or more comets are now known to move in parabolic paths. Whence they come and whither they go no man knows. In far-off regions of space the

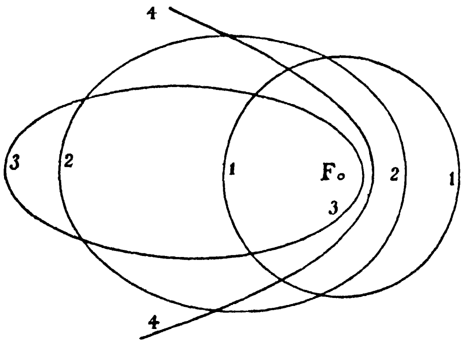


FIG. 38.—1, a circle; 2, an ellipse; 3, an ellipse with large eccentricity; 4, a parabola.

sun's influence is felt. A comet is beckoned by the sun and begins its journey to our system, moving tardily at first, but slowly and surely increasing its speed. A year, ten years, or it may be a hundred years, pass before the traveller comes in sight. With great rapidity it swings around the sun, and then away into the darkness of infinite space it goes, and may be lost to us for ever. To use the simile employed by one of King Edwin's men to the life of a man, " It is as a sparrow's flight through the hall when you are sitting at meat in winter-tide, with the warm fire lighted on the hearth, but the icy rain storm without. The sparrow flies in at one door, and tarries

for a moment in the light and heat of the hearth fire, and then flying forth from the other vanishes into the wintry darkness whence it came."

The only difference between the path of a periodic comet and that of a planet is in the form of the ellipse. The comet's ellipse is much elongated—the foci are separated by a considerable distance—whereas in a planetary ellipse the foci are comparatively near together. In each case,

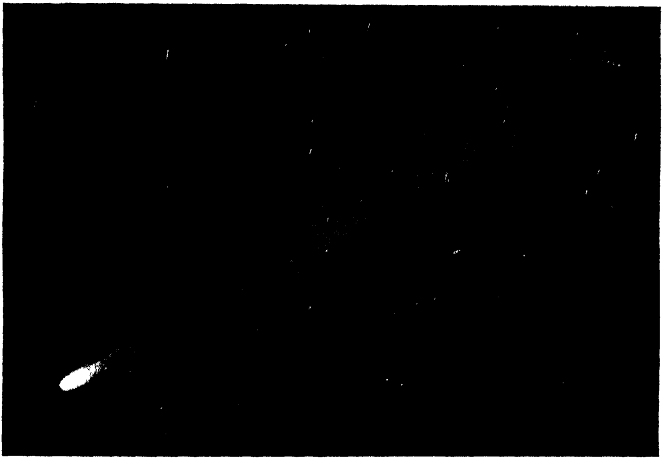


FIG. 39.—Photograph of Halley's comet, taken by Prof. E. E. Barnard, on May 4, 1910.

however, the sun is situated in a focus of the ellipse, and from this it follows that the comet's greatest and least distances from the sun are enormously different. Mercury has the most eccentric orbit of the planets, the difference between its greatest and least distances amounting to 15 million miles. Halley's comet is 56 million miles distant from the sun at its point of nearest approach, and 3,200 million miles away when at the opposite end of its orbit. The difference between the greatest and least

distances is thus 3,144 million miles. Halley's comet has been traced back to the year 87 B.C. and is believed to be identical with a comet seen in the year 240 B.C. It was last seen in 1910, and will return again in 1985.

Halley's comet comes like an illustrious foreigner, in pomp and splendour, but its visits are "few and far between." There are other comets which are much more modest both in tour and appearance. One of these was discovered by a well-known comet observer, Pons, in 1819, and its orbit was calculated by Encke. This—the second comet proved to be periodic—makes a call upon the sun once in three and one-quarter years, but without any display. Indeed, it is usually invisible to the naked eye, even at its brightest. The comet is 32 million miles from the sun at the point of nearest approach, and has a distance of 387 million miles when most removed from our luminary. Jupiter's distance is 483 millions of miles, so the comet's orbit is inside that of the giant planet.

Comets admit of being classified according to their orbits. First there are those which move in parabolas, and rush away after making a rapid visit to our part of the universe. The majority of comets travel in curves of this kind. Next we have the comets which, as it were, pay a visit to the sun once a century or so—comets of long period. Forty comets, more or less, belong to this class. In addition, there are something like twenty comets which move round the sun once in less than ten years, and are known as comets of short period.

Parabolic comets behave like excursionists to the solar system. They come out of all parts of space, and mostly travel round the sun in a right-handed fashion, but some have a left-handed direction of motion, like the planets. With a few exceptions, all the comets having elliptical orbits move in the latter direction, in this uniformity differing from the parabolic type.

As to the origin of comets, one view is that periodic comets have been captured by our solar system: they

are immigrants from outer space, and not natives like the planets. Attracted by the sun, they swoop towards us in beautiful parabolas, but with no intention at all of staying. Occasionally, however, one of the major planets happens to be near the line of travel as the celestial visitor hurries along it. When the two bodies are so situated that the comet is held back slightly by the attraction of the planet, and after several such experiences, the parabolic

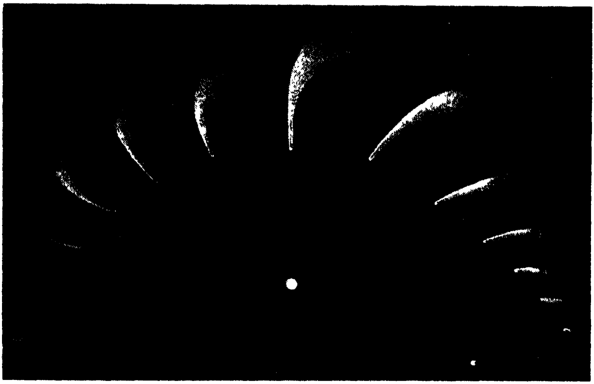


FIG. 40.—On account of the pressure exerted by light upon extremely fine particles, the tail of a comet is always directed away from the sun.

orbit becomes transformed into an elliptical one. The vagabond is thus made a prisoner, having been captured by a planet, and instead of flitting away again into realms unknown, it is forced to march along a certain track and report itself periodically.

Though, on the average, only three or four brilliant comets appear in a century, many more are observed telescopically; indeed, scarcely a year passes without half a dozen being discovered. A telescopic comet has the appearance of a small patch of mist in the sky, and cannot be distinguished from one of a large class of celestial

bodies known as nebulæ. It is impossible to say from the first observation whether the object will become conspicuous or not. In general, as a comet approaches the sun, a slight brightening is observed near the centre, and this becomes concentrated to a star-like nucleus, from which luminous gases may be ejected in the form of jets and envelopes. This luminous matter is driven back as if repelled by the sun, and goes to form the comet's tail. The strong repulsion away from the sun of the material of which a comet's tail is composed is in all probability due to the pressure which light exerts upon very fine particles, so that sunlight sets upon the constituents of the tail like a strong wind upon chaff, and the different shapes assumed are due to the different nature of these constituents. It results from this effect that the tail is pointed away from the sun no matter what position the comet occupies in its orbit. When the sun is being approached, the tail follows the head, but when the comet is receding the tail goes first. The repulsive force due to light depends upon the size of the particles acted upon, and in certain circumstances may be thirty times that due to gravitation.

Many comets attain enormous dimensions. The great comet of 1858 grew from a small patch of nebulosity until its head was a quarter of a million miles in diameter, and its tail more than fifty million miles in length. In spite of this great show, however, comets are not weighty bodies. One hundred thousand of the largest comets ever observed would not weigh as much as the earth. Since the volume or bulk of a comet is so great, and the mass of the whole object is so insignificantly small, the mean density must be less than anything of which we have any conception. Suppose we could take a comet, head, tail, and all, and put it in one pan of a balance, and we could carve out from the air which surrounds us an object of the same size to put in the other pan, we should find that our aerial body weighed four or five thousand times more than the

comet. But though a comet as a whole is lighter than air, it must not be concluded that comets consist solely of gases in a state of extreme tenuity. The head may be, and very probably is, composed of a large number of small but solid bodies; nevertheless, when a comet is taken

FIG. 41.—Photograph of the Great Comet of 1882, obtained by Sir David Gill at the Cape Observatory. The first comet photographed.

in its entirety, the mean density is extremely low. A convincing demonstration of this spiritual texture is afforded by the fact that stars suffer no obvious change of place or brilliancy when a comet passes in front of them. The earth has on more than one occasion passed through

the tail of a comet without any marked effect being observed.

The attenuated character of the tails of comets is very clearly manifested in photographs, such as that of the

Fig. 42.—Photograph of Morehouse's Comet, taken on October 3, 1908, at the Royal Observatory, Greenwich.

Great Comet of 1882 (Fig. 41), which was the first to be photographed. It will be seen that the stars are all elongated in one direction. The amount of elongation represents the distance through which the comet moved during the time of exposure. Comets, as we have before

remarked, are celestial vagabonds. They have no fixed abode upon the vault of heaven, but wander from point to point. In order to photograph the comet, therefore, the telescope has to keep time with it instead of with the stars, and the length of the trails of the stars upon the photographic plate is an indication of the duration of the exposure.

The spectroscope shows that comets are, to a very large extent, self-luminous, and that the constituents which manifest themselves in the most decided manner are carbon and its compounds. This fact is not without interest, for all animal and vegetable substances contain carbon in some form or other. It must not for a moment be supposed, however, that astronomers of the present day believe comets to be the abode of life because carbon exists in them. One ancient astronomer said that they could not be abodes of happiness, but "places of punishment for the wicked, who were alternately wheeled into regions of intolerable heat and afterwards exposed to all the regions of the most intense cold."

Who has not been startled when looking on the sky at night by seeing a shooting-star? A point of light glances across the sky, leaving a luminous trail which hangs in the heavens for a few seconds and then disappears. To all appearances a star has fallen from its place in the celestial vault, but of course this is not so. The word star applied to such a transient object which sparkles and dies in a moment is a libel upon the mighty suns fervidly shining in infinite space. Shooting-stars are small particles of matter revolving round the sun like the earth. Our globe is constantly plunging into these specks of cosmic dust and attracting them towards itself. The consequence is that they enter our atmosphere with an average velocity of about thirty miles a second. A rifle bullet becomes hot in passing through the air, though its velocity is far less than this. It can easily be understood, then, that a particle which enters

the earth's atmosphere at the terrific speed of thirty miles a second, must become very hot by friction against it. In fact, the heat developed is sufficient to melt and vaporize the solid particle, and its dissipation in this manner produces the phenomenon of a "shooting-star."

Observations indicate that space is filled with fragments of this kind, and it is estimated that something like 400 millions of solid particles rain down upon the earth and are consumed in the atmosphere daily.

When two or more observers see the same shooting-star from different places, and notice the length and direction of the trail, the height at which the particle commenced to be luminous and that at which it was entirely burnt up can be calculated. The average height at which luminosity commences is about seventy-six miles, and extinction usually occurs at a height of about fifty-four miles.

Closely allied to shooting-stars are the brilliant meteors or fire-balls occasionally seen. The difference between the two classes of bodies is very probably only one of size, for both owe this luminosity to friction against the earth's atmosphere. Fire-balls, being larger portions of matter than shooting-stars, present a larger surface to the atmospheric brake, and, as a result, become luminous at a greater height above the solid ground. They are also not consumed so readily, the average height at which all the material is dissipated into vapour being thirty miles. Some of the meteors are so large that they reach the earth's surface before sufficient heat has been developed to drive them entirely into vapour. These celestial missiles which penetrate the torpedo-net of the earth's atmosphere are known as "meteorites." There are a number of well-authenticated records of such falls from heaven, though it was not until the beginning of last century that their celestial origin was believed in.

In the tenth chapter of Joshua we read, "The Lord cast down great stones from heaven," and, if this refers to a fall of meteorites, it is the earliest record of such an

occurrence. Livy mentions a fall of meteorites which took place about 650 B.C. In the words of this Roman historian, "News was brought to the king and the fathers that it had rained stones on the Alban Mount. Wherefore, though it seemed scarcely credible, when men were sent to observe the portent, stones fell thickly from heaven in their sight." The fall was accompanied by a "mighty noise," which was interpreted as a manifestation of the displeasure of the gods, so a nine days' solemn festival was held. Other falls from the sky are mentioned by early writers, and many of the stones were worshipped as "holy things fallen from heaven."

The oldest undoubted meteorite now in existence is suspended by a chain in the parish church of Ensisheim in Alsace. The excellent guide to the meteorites in the Natural History section of the British Museum contains the following account of the meteorite at Ensisheim, being a translated extract from a document kept in the church. "On the 16th of November, 1492, a singular miracle happened; for between eleven and twelve in the forenoon, with a loud crash of thunder and a prolonged noise heard afar off, there fell in the town of Ensisheim a stone weighing 260 pounds. It was seen by a child to strike the ground in a field near the canton called Gisguad, where it made a hole more than five feet deep. It was taken to the church as being a miraculous object. The noise was heard so distinctly at Lucerne, Villing, and many other places, that in each of them it was thought that some houses had fallen. King Maximilian, who was then at Ensisheim, had the stone carried to the castle; after breaking off two pieces, one for the Duke Sigismund of Austria, and the other for himself, he forbade further damage, and ordered the stone to be suspended in the parish church."

The largest mass in the collection of the British Museum weighs about three and a half tons, and was found at Cranbourne, near Melbourne, Australia, about 1854.

Among the chemical elements frequently found in meteorites are iron, nickel, sulphur, carbon, silicon,

FIG. 43.—A meteorite weighing 3½ tons, which fell at Cranbourne, near Melbourne. Now in the Natural History Museum, South Kensington.

magnesium, and aluminium, while among those less plentiful are titanium, manganese, cobalt, tin, and copper.

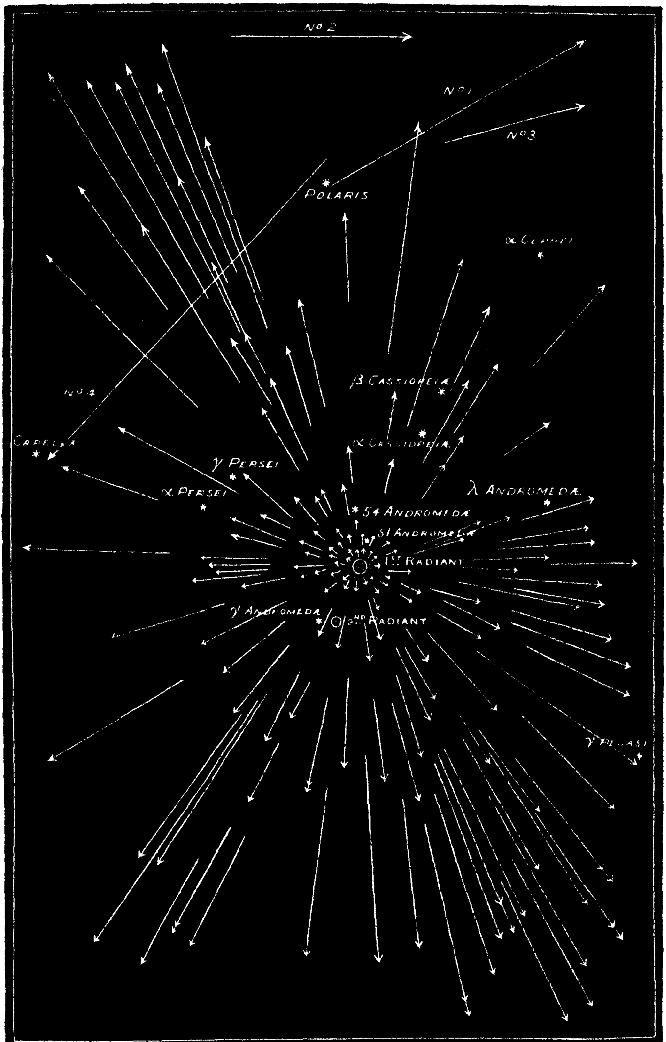


FIG. 44.—Meteors of November 27, 1872, showing how they radiate from one point in the heavens.

There are three forms in which carbon occurs on the earth, represented respectively by lamp-black, black-lead, and diamond, and each has been found in meteorites. Usually carbon occurs in one of its compound forms, and sometimes in forms which would be taken as an indication of animal or vegetable existence if found upon the earth. The iron of meteorites usually occurs alloyed with nickel, and is never found alone. Though no new element has been discovered in meteorites, many combinations, entirely unknown in the crust of the earth, occur in them.

There is every gradation between the fire-ball which rushes through the air and reaches the ground as a meteorite, and a noiseless shooting-star, but the two may represent only varieties of one phenomenon. Usually shooting-stars are seen one at a time, and they glance across the sky in any direction. At regular intervals, however, we see " the vaulty top of heaven, figured quite o'er with burning meteors." A circumstance which soon attracts the attention of an observer of a great shower of this description is that all the meteors appear to shoot away or radiate from a particular part of the sky, known as the " radiant " or " radiant-point." Even when showers of a less remarkable character are observed, when perhaps only one or two meteors are seen at the same instant, the streaks point backwards to a radiant. Near the radiant the meteors have very short trains, while those farther away are visible over long tracks. This is explained as an effect of perspective. When we look through a long straight gallery or tunnel, the roof, floor, and sides are seen to converge to one point, known to artists as the " vanishing-point." The radiant-point is similarly produced. The meteoritic particles are travelling in practically parallel paths when the earth plunges in among them. Owing to the brake put upon their motions, the meteors leave behind them a luminous trail of the paths they pursue, and when we look through all these parallel streaks we see them converging to a " vanishing-point " in the sky, just as the parallel

walls, floor, and roof of the tunnel were observed to do. Hence the radiant marks the actual direction of motion of the meteors when the earth meets them.

About the middle of November every year a certain number of shooting-stars are seen to radiate from a point in the constellation Leo, and ancient chronicles record brilliant displays of meteors from this part of the sky at intervals of thirty-three years. It appears from this that the meteors belong to a stream of particles which journey round the sun once in thirty-three years, in an orbit which crosses the orbit of the earth. When both reach the "level-crossing" together a meteor shower testifies to the encounter, the brilliancy of which depends upon the degree of concentration of the meteoric particles in the part of the orbit crossed.

The meteors which radiate from the Lion constellation are known as Leonids. The stream of solid particles which produces them is more concentrated at one part of the orbit than elsewhere, and this accounts for the brilliant displays seen in 1866 and 1833. A certain number of Leonid meteors are seen, however, about the middle of November every year. At the end of November once in thirteen years showers are observed in which the meteors radiate from a point in the Andromeda constellation. These particles therefore travel round the sun in a period of thirteen years. Slight showers occur about the beginning of August in every year, reaching a maximum on August 10th. This is because the meteoritic particles extend completely round the sun, so there are always some in the way of the earth as we pass through the point where the meteor orbit cuts ours. These meteors radiate from the constellation of Perseus. Another well-known shower happens in April, the radiant in this case being in the constellation of the Lyre.

At the beginning of 1866 a comet was discovered by Tempel, and the form and position of its orbit was calculated. Shortly after the memorable meteor shower of

1866, it was pointed out that the orbit of the Leonid swarm was precisely the same as that of Tempel's comet. There could be no doubt about the matter: in form, dimensions, inclination to the ecliptic, and position, the orbits of meteor swarm and the comet were identical. Only one conclusion could be drawn from this coincidence, namely, that the comet was part of the meteoritic stream. It was afterwards shown that the orbit of the August meteors, the Perseids, was identical with that of the great comet of 1862. This, then, was a second clear case of association of a comet with a swarm of meteorites. A third coincidence of a similar character is still more striking. It is the case of Biela's comet which split in two parts in 1845 and 1852 and has not been seen since, though it has a period of only about six years. On November 27, 1872, and on the same day in 1885 and 1892, when this comet should have appeared, shooting-stars showered copiously from a point in the constellation Andromeda. Calculations show that the orbit of this swarm is identical with that of the lost comet, and the Andromeda meteors are now often called Bielids.

Another interesting example of this kind is afforded by Pons-Winnecke's comet, which has a period of a little more than five and a half years. In June, 1916, about ten months after this comet had passed its nearest approach to the sun, a shower of meteors was observed having a radiant-point corresponding with the position of the comet's orbit, though some distance behind the head, and there is reason to believe that these were due to an encounter with solid particles in the comet's wake. The comet returned again, however, in April, 1921, but it passed outside the earth's orbit, and no meteor shower was seen.

It is believed by some astronomers that meteorites are portions of matter ejected from volcanoes on the earth, moon, and planets, and that periodic comets are also products of eruptions, hurled into space with such force

that they got outside the sphere of attraction of the body which gave them birth. A velocity of six miles a second suffices to carry a body beyond the domain of terrestrial influence, and one mile a second in the case of the moon. so that eruptions in former times might conceivably have ejected matter beyond the sphere of influence of the bodies on which this occurred.

A comet in passing around its orbit undergoes various transformations which are explainable on the assumption that comets are swarms of solid particles or meteorites. A cloud of meteorites is pulled into the solar system from interstellar space, and is first seen as a fairly luminous haze. The luminosity may be produced by the meteoritic particles jostling one another, and thus provoking sufficient heat to volatilize their constituents. The swarm moves onward, and by the increased intensity of gravitational attraction, the individual particles are caused to move faster, and, therefore, to collide and graze against each other more frequently, the result being an increase of brilliancy. As the temperature rises, and a greater amount of heat is developed, as well probably as electrical action, the vapours are given off in sufficient quantity to form a tail. Usually the appendage increases in size until a few days after the comet has passed its point of nearest approach to the sun, and then diminishes. The collisions gradually become less violent and less frequent when the swarm is leaving the sun, and, finally, the commotion has decreased to such an extent that only a feeble luminous haze tells of the swarm's existence.

Though the superstitious fear of comets has died away, a dread exists in the minds of many people that the earth will some day pass through the nucleus of one. There is certainly a possibility of this happening, and Prof. Simon Newcomb estimated it in this manner, "There is hardly a possible form of death which is not a thousand times more probable than this. So small is the earth in comparison with the celestial spaces, that if one should

shut his eyes and fire a gun at random in the air, the chance of bringing down a bird would be better than that of a comet of any kind striking the earth."

It is difficult to say what the result of running full tilt into a comet's nucleus would be. If the nucleus consist merely of "cosmic dust," only a brilliant shower of shooting stars would be seen; but if it is made up of bodies as large or larger than cannon-balls, the consequence would be serious. Myriads of the meteoritic masses would beat upon the earth, and the burning of the materials of which they are composed would probably use up the oxygen in the atmosphere, in which case, man and all the animal creation would perish. The temperature of the air would also be raised to such a degree that all vegetation would be destroyed and our world would be transformed into a desolate and barren rock. The prospect is not a pleasant one, and consolation may be found in the fact that an encounter such as that referred to only has a chance of happening once in about twenty millions of years.

CHAPTER VIII

IN THE DEPTHS OF SPACE

ABOVE and below the system of the sun, to the right and to the left of it, roll the stars, which are the poetry of heaven. They are suns like our own, inasmuch as they shine with unborrowed light, and possibly each " informs a system in the boundless space," like that of which the earth is a part. The sun is more brilliant than any star, solely because it is nearer to us. If it could be taken away from us, into the infinitude of space, it would apparently lose its magnificence ; and at the distance of the nearest star it would have dwindled to a lucid point like the pole star, which for ever twinkles in the northern sky.

As soon as Galileo turned his telescope towards the heavens, he saw revealed a host of stars on which no human eye had previously gazed. In his " Sidereal Messenger " he gives a few examples of these virgin regions. His own description of what he saw in one such field is as follows :—

" I have selected the three stars in Orion's belt and the six in the Sword, which have been long well-known groups, and I have added eighty other stars recently discovered in their vicinity, and I have preserved as exactly as possible the intervals between them. The well-known or old stars, for the sake of distinction, I have depicted of larger size, and I have outlined them with a double line ; the others, invisible to the naked eye, I have marked smaller and with one line only. I have also preserved the difference of magnitude as much as I could."

By the invention of the telescope, then, the number of observable stars was enormously increased. To the naked eye, between two and three thousand stars can be seen at one time and place. In the portion of the celestial sphere visible from middle latitudes, about fourteen stars are

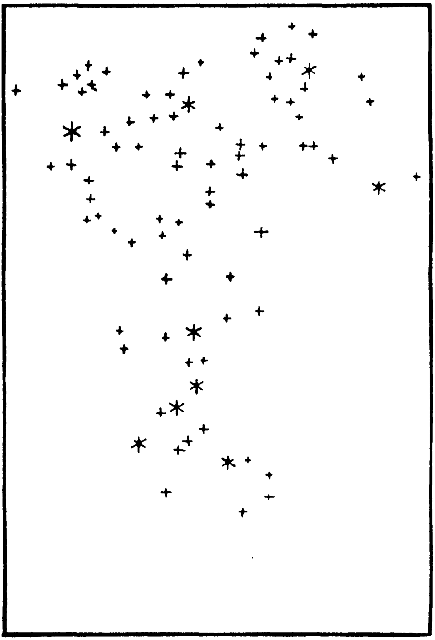


FIG. 45.—Galileo's observations of stars in Orion. None of the eighty stars with four rays had been seen by human eyes before Galileo observed them with his telescope.

conspicuously bright; fifty shine with a light equal to that of the Pole Star, and two thousand are just visible. Stars are classified into "magnitudes" according to their glory. Taking the twenty brightest stars in the heavens, the average of their brightness is used as the standard

first magnitude. Aldebaran is an example of a star of the first magnitude; the pole star is of the second magnitude, and stars on the verge of invisibility belong to the sixth magnitude. The range of unaided vision thus includes six magnitudes; and an average star of the first magnitude is one hundred times brighter than one of the sixth magnitude. This gives astronomers an arbitrary scale on which stellar magnitudes are graded. The light of a star of any magnitude is to the light of a star one magnitude fainter as about two and a half is to one. Hence two and a half stars of the sixth magnitude equal in brightness a single star of the fifth magnitude; two and a half of the fifth equal one of the fourth; and so on until we arrive at a star of the first magnitude, that is, one which sparkles with one hundred times the intensity of a star which can just be seen on a clear night. Telescopic stars are similarly graded, according to the light received from them.

The total light received by the earth from stars visible and invisible to the unaided eye is extremely small, being only about equal to that of a single candle viewed from a distance of nearly twelve yards. It is therefore merely a poetic fancy to suppose that the stars were created to light the earth. As Lytton tersely put it, " A farthing candle is more convenient for household purposes than all the stars."

Why is it that " one star differeth from another in glory?" The first explanation which suggests itself is that the difference in brightness is caused by difference of distance from the earth. A first magnitude star removed to ten times its present distance from us would glimmer as a star of the sixth magnitude, and if taken far enough into the depths of space, it would sink beyond the reach of our largest telescopes. Hence, if it could be assumed that all the stars were equal in size, and the difference in brightness was the result only of difference in distance, it would be possible easily to estimate the relative distances

of stars from the earth. There are, however, great differences in the sizes of the stars; moreover, the measures of stellar distance show that many bright stars are much farther from the earth than fainter ones. Stars are seen in the heavens in bunches, and though there is evidence that the individuals are at approximately the same distance from the earth, some of them are brilliant while others are scarcely visible in the best of telescopes. The intrinsic luminosity of stars also differs on account of the difference in their temperatures. There are intensely hot stars, and stars which have lost their power of shining, owing to their cooled condition, and every gradation exists between the two classes. It cannot, therefore, be said definitely that one star is fainter than another because it is more distant from us, or because it is smaller, or because its surface is less luminous, for each of these causes affects the result.

In order to compare the intrinsic brilliancy of one star with another, they must be imagined at the same distance from the earth. When stars of which the distances are known are compared in this way, by calculating their brightness at a standard distance, and thus reducing them to a common scale, what is known as the *absolute magnitude* is obtained to distinguish it from the *apparent magnitude* determined by ordinary observations.

The determination of the distances of stars is one of the triumphs of modern astronomy. The principle of the method is simplicity itself. To find the distance of a terrestrial object without direct measurement, theodolites are taken to each end of a line, the length of which is known, and pointed to the object, and from the observations the required distance can be found. If two theodolites, say, ten miles apart, are pointed at a particular star, it might seem that the distance of the star could be calculated in the same way as that of the terrestrial object. Observations of this kind would show, however, that the two theodolites were parallel, proving that the star has no

parallactic displacement when viewed at the two extremities of a line ten miles long. Lengthen the base-line to one hundred miles, and again a negative result is obtained. Even when the star is observed from the ends of a diameter of the earth, that is, at the extremities of a base-line eight thousand miles long, no displacement is found. But there is another base-line which, it might reasonably be expected, would be long enough for the determination of distances of almost infinite magnitude; it is the diameter of the earth's orbit.

The earth is at a particular part of its orbit at the present moment; in six months it will be on the other side of its orbit, the distance between the two points being about 186 millions of miles. If, then, a telescope is directed to a star at an interval of six months, it would seem that a very definite parallactic displacement ought to be observed. So it seemed to Tycho Brahe, and Galileo, and to Hooke, Molyneux and Bradley, Herschel, and many other pioneers of astronomy, yet time after time was the observation made without a single accurate result being obtained. The failure was due partly to the imperfections of the instruments employed in the measurement of minute dimensions on the celestial sphere. It was not until 1838 that the problem which had engaged the attention of astronomers since the time of Copernicus was satisfactorily solved.

The general principle of direct methods used to determine stellar distances is easily understood. On account of the movement of the earth in its orbit, we constantly observe the stars from different points in space. Once a year only do we see them from the same place. For this reason each stellar point is projected upon different parts of the infinite celestial sphere throughout the year. Suppose that on every night in the year a straight line could be drawn from the earth through a star to the celestial sphere, then the ends of the lines would mark out a figure upon the

sphere exactly like that of the earth's orbit. The nearer a star is to the earth, the greater is the size of this apparent ellipse, known as the "parallactic ellipse." Each star appears to describe a minute ellipse of this character, traversing its apparent path annually. It must not for a moment be supposed, however, that these apparent lines

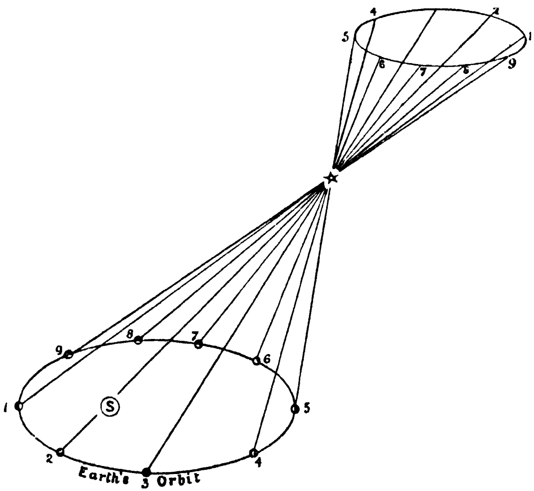


FIG. 46.—Parallactic ellipse of a star due to the annual revolution of the earth around the sun.

of travel can be detected with the naked eye, or that they alter the configuration of the constellations during the year. They are so small as almost to defy detection even with the most refined means of telescopic measurement.

To determine the size of the parallactic ellipse of a star, measures are made of the star's exact position (Right Ascension and Declination) throughout the year. A number of corrections have then to be applied to the

observations. When this has been done, if the star is not at an infinite distance from the earth, the positions will be found slightly different on different dates, and by plotting the points upon a large star-chart, they will be found to range themselves in the form of a minute ellipse. The angular dimensions of half the longest length of this ellipse is the parallax of the star under observation. It represents the angle contained between two lines drawn from the star—one to the sun, the other to the earth. This method of determining stellar parallax is known as the "absolute" method, because absolute observations of position are made. Unfortunately, it does not give the best results. The vitiating causes are so many, and their effects are so large and imperfectly understood that a star's parallactic ellipse cannot generally be extricated from the tangle.

The "differential" method of determining parallax is free from many of the difficulties which belong to the observation of absolute places of stars, and is the one now usually employed. Let us give an illustration of the principle underlying it. Imagine yourself in a field and looking towards a tree a few hundred yards away. The tree appears in a line with others a considerable distance off. By changing the point of observation, the nearer tree will appear in a line with different trees in the distance. The trees may be considered to represent stars, and by walking in a circle, the motion of the earth in its orbit can be imitated.

Just as a tree appears to change its place with respect to more distant trees as the observer moves round his path, so a star must appear to vary its position with reference to others deeper in space, in consequence of the earth's orbital motion. A difference exists, however, between the two cases. There is no difficulty in telling which tree is near and which is at a distance, but no sure indication of this kind is exhibited by the stars. It is necessary to assume that the faint stars apparently near

the one of which the parallax is desired are so far away that they can be considered as reference points upon the celestial sphere. The positions of the selected stars with respect to these points are determined throughout the year instead of finding the exact situation in the heavens from time to time. The difficulties which affect the result in the absolute method are thus entirely obviated, for they affect all the stars alike. When such measures are made and mapped, the star under observation is found to describe a parallactic ellipse relatively to the faint ones near it. In no case, however, can the true parallax of the star be obtained by this method, but only the difference between its parallax and the parallaxes of the reference stars.

Instead of determining visually the relative positions of stars surrounding that selected for observation, when the objects are in the field of view of the telescope, a photograph may be taken, and the relative positions of the stars upon it be afterwards measured at leisure. The photographs have the advantage of being permanent records, so that the measures can be verified if necessary, whereas measures made while the observer is at the telescope have to be taken on their merits, for it is impossible to realize exactly the same conditions of observation at any future time.

An important method of obtaining the parallaxes of stars by a very different method has recently been developed by Prof. W. S. Adams of the Mount Wilson Observatory. The method is an indirect one and has for its object primarily the determination of the absolute magnitudes of stars, that is, the apparent magnitudes which stars would have if they were all at a distance from the earth represented by a parallax of one-tenth of a second of arc. It has already been shown that the stars vary greatly in their true brightness or "absolute magnitude," and that the differences of brightness which appear to exist are not due simply to the different distances of

the stars. If the distance of a star is known, of course its absolute magnitude can at once be calculated from a knowledge of its apparent magnitude; and it is easily seen that if by any independent means we could arrive at a knowledge of its absolute magnitude we should be able to reverse the process and determine the star's distance. This is the principle of Prof. Adams's method. He discovered that a difference of absolute magnitude between two stars is indicated in their spectra by a corresponding difference of intensity of certain lines, and he was thus enabled to perfect a method whereby the absolute magnitude, and hence the parallax, of a star could be obtained fairly accurately by means of a careful examination of its spectrum. This method is comparatively easy and rapid, and is of great value—especially as a check on results obtained in other ways, and in giving us information with regard to stars at a distance too great to be measured by the older methods.

There are other less important methods by which an approximate idea of stellar distances may be obtained, two of which may be briefly mentioned here. One of these resembles the first method described above, except that instead of the parallactic ellipse the quantity to be measured is the apparent motion of a star due to the motion of the solar system as a whole (called the star's "parallactic motion"). This cannot give such accurate results, since the true direction and speed of motion of the solar system is not accurately known; but the accuracy increases continuously as the distance increases through which the sun has travelled since the time when accurate instrumental measurements were first introduced. The method cannot be applied to individual stars, since a star's "peculiar" motion—that is, its true individual motion—is not known unless its distance is also known; but it is useful in giving us information concerning the average distance of a group of stars.

The second method referred to is the utilization of

double-star observations (see next Chapter). If the distance of a " binary " system is known the combined mass of its components can at once be deduced, and it is found that this mass does not differ very greatly from one system to another. If, then, we assume, for any particular binary system, a combined mass of the two components equal to the average value of the mass of such systems, we could determine its distance with moderate accuracy.

It will be noticed that the last three methods just described depend, in their practical application, upon the known values of the parallax of a few special stars ; and on this knowledge a system is erected for determining other parallaxes which are unknown. These standard parallaxes must be obtained by the original method first described (called the " trigonometrical " method), which is therefore fundamental in the problem of stellar distances, and is the only *direct* method of attack.

In 1838, Bessel completed a series of observations of the position of a star known as 61 Cygni, barely visible to the naked eye, with respect to a couple of fainter stars near it. The result showed that half the greatest length of the parallactic ellipse, that is to say, the parallax of the star, was about one-third of a second of arc. To put it another way, if an astronomer were on the star, the angle between the two directions in which he would have to point his telescope to view the earth and the sun respectively would be about one-third of a second of angular measure. How minute this angle is may be judged by an illustration.

The long hand of a watch or clock moves through a circle of 360 degrees in an hour ; in one minute it moves through an angle of six degrees ; in one second through one-tenth of a degree, that is, six minutes of arc. Following up this proportion, it will be found that the minute hand, if moving uniformly and not in jerks, would pass through an angle of one-third of a second of arc in about one-thousandth of a second of time.

In other words, the difference between the directions of a continuously moving minute hand of a watch or clock at the beginning and the end of one-thousandth part of a second represents the parallax of the star 61 Cygni. We can go further and say that up to the present time no star is known to have a parallax of more than one second of arc—an amount through which the minute hand of a watch would move in the three hundred and sixtieth part of a second.

About the same time as Bessel's results were published, Struve, using the same differential method, found a parallax of about one-fifth of a second for the bright star Vega; and Henderson, by a discussion of absolute measures of position, showed that the star Alpha Centauri, invisible in the northern hemisphere, has a parallax of rather less than one second of arc.

When the parallax of a star is known, the corresponding distance in miles can be calculated. It can be proved geometrically that any object viewed at a distance of 206,265 times its own length subtends an angle of one second. Thus, a halfpenny has a diameter of an inch, and if the coin is taken to a distance of 206,265 inches, that is, 3¼ miles, the angle between two pointings of a telescope, one to the upper and the other to the lower edge, is one second of arc. Suppose, then, an observer on a star found that the angle between two pointings to the earth and sun respectively was one second; if he knew that the distance from the earth to the sun was 93 millions of miles, he would be able to find the distance of his globe from us, for it would be 206,265 times 93 million miles.

Remembering this relation between angles and distance, and also that the parallactic angles are inversely proportional to the distances, it is easy to find the distance of a star after its parallax has been measured. As no star yet measured has a parallax so great as a single second of arc, no star is as near to us as 206,265 times 93 million miles,

that is, about 19 millions of millions of miles. The star 61 Cygni is at three times this distance; Vega is at five times this distance.

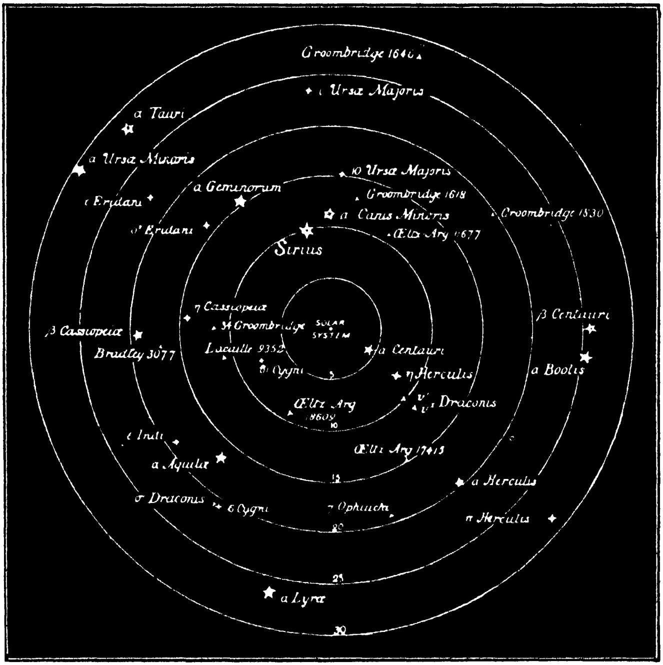


FIG. 47.—Distances of some stars from the solar system. The numbers on the circles represent "light-years."

The immensity of these numbers cannot be easily conceived. To bring them within the mental grasp, astronomers employ a unit of length vastly longer than anything used in terrestrial measurements. It is the distance which light travels in a year, and is called a "light-year." In a second of time a beam of light flashes

through a distance of 186,000 miles. The total distance traversed in a year at this rate of motion, namely, six million million miles, provides a useful unit for expressing stellar distances.

Another unit now used by astronomers is the distance represented by a parallax of one second of arc. This is called a "parsec," and it represents three and a quarter times the distance of a light-year.

Upon many maps of towns and suburbs, circles are drawn showing distances in miles from a centre. A plan of stellar distances may be constructed upon this principle, taking the solar system as the centre, but instead of drawing circles representing radii of one, two, three miles, and so on, the distance from the solar system to each circle may be represented by the span of space through which light flashes in intervals from five to thirty years. We are thus able to exhibit upon a map the stellar distances at present known with any degree of accuracy. Of all the stars, relatively few have had their distances determined, and in the accompanying diagram (Fig. 47) those at distances less than that through which light travels in thirty years are shown in their proper relative positions round the sky. More than this, the illustration shows the number of miles the stars are distant from the sun, if the earth's distance were represented by a length of one inch. Alpha Centauri is the nearest star. A flash from the sun to it, or vice versa, only takes four years to reach its destination. The light we receive from Vega at the present time left the star on its journey twenty-seven years ago. Or, to put it another way, if the earth is represented by a minute speck of dust revolving round a grain of sand at a distance of an inch, Vega would be a similar grain twenty-seven miles away. Most of the stars seen in the sky without telescopic aid are at such a distance that the light we now analyse left them about the time of Galileo; and there are others whose rays, though rushing with lightning speed through the depths of space, only reach us after

a journey counted in thousands of years. We are in a "universe of endless expansion" and through it messages of light may be sweeping from bodies so far sunk in the empyrean that they will never be received by the eye of man.

CHAPTER IX

INCONSTANT STARS, CLUSTERS, AND FORMLESS MIST

THE appearance of the sky on a fine night gives one the impression of infinite calm and peace, and it scarcely appears credible that each star is in a state of tumult, and that all are moving rapidly through space; yet such are the facts. The stars have apparent motions belonging not to them but resulting from the movements of the earth. They also have "proper motions," that is, real motions which go on quite independently of terrestrial changes of position. When a vessel is watched on the distant horizon, it appears to move only very slowly, even though the real speed may be great, and, indeed, several minutes may pass without any change of position being detected. Similarly, the stars are so far away that their real motions are scarcely observable, and can only be discovered by watching the skies over a long period of time.

Hipparchus made a catalogue of the positions of some of the stars about 125 B.C. Eighteen hundred years later Halley compared these positions of celestial bodies with those found in his day. The comparison showed that unmistakable changes of position had occurred during the interval. The difference between the old and new positions of Sirius, the brightest star in the heavens, was as much as the apparent diameter of the moon, and other stars exhibited similar and even greater discrepancies. The numerous observations made by Hipparchus of the same star precluded the idea that he had been mistaken in his measures; and it was concluded that the stars

themselves had moved. Measurements made since the time of Halley have established the fact of this motion, and, in all good catalogues of stars now compiled, the amount by which each individual star changes its position in a year is stated. A " fixed " star is, indeed, unknown.

The result of this proper motion is that configurations of stars change with the lapse of ages. To the eye, the Great Bear constellation appears much the same to-day as it did when Hipparchus observed it more than two thousand years ago. But in, say one hundred thousand years, the familiar Plough, mighty Orion, Cassiopeia's Chair, and other constellations, will have lost their present alignments and be unrecognizable.

Until a few years ago the star having the largest known proper motion was No. 1830 in a catalogue made by Groombridge, and known, therefore, as 1830 Groombridge. It is situated in the Great Bear, but is invisible to the naked eye. In a year this star moves through seven seconds of arc; in a century therefore it moves through seven hundred seconds, and in about 185,000 years it will make the circuit of the celestial sphere. In 1916, however, Prof. E. E. Barnard discovered a faint star having a proper motion of ten seconds of arc in a year; and, as the apparent angular diameter of the moon is 1865 seconds, the star will pass over this distance in about 186 years. The star 61 Cygni, to which reference has previously been made, has a proper motion of half this amount. It was on account of the existence of this comparatively large proper motion that Bessel was led to select this star for observations of parallax. If the velocities with which stars move across the line of sight were equal, then a large proper motion would be an indication of nearness to our system, but this criterion is no more certain than that obtained from a consideration of stellar brightness. It is found, however, that stars of certain types are nearer to us than other stars.

The stars possess proper motion; the sun is a star,

therefore the sun has a proper motion; this is a logical conclusion which presented itself to the mind of Sir William Herschel and which he established by observation. He proved that the sun with its planets and satellites is moving towards the constellation Hercules. A number of determinations have been made of the point towards which the sun is travelling (known as the "apex of the sun's way") by various astronomers, and, considering the difficulty of the problem, the agreement is remarkable. The apex appears to be a point in the sky close to the bright star Vega, and the velocity with which the sun is moving towards it is about twelve miles a second. When we compare this with the velocity with which a shell is ejected from the most powerful gun it seems enormous. Such a comparison, however, leads to erroneous ideas. A shell which took a day to move through a space equal to its own length is travelling at less than a snail's pace; yet, with a velocity of twelve miles per second, the sun takes nearly a day to move through a space equal to its own diameter.

In order to understand the conditions of the problem of the sun's movement through space, consider an observer to be in a large park among a concourse of people. The people are moving about in all directions, but a general movement is also noticed away from the entrance gate of the park and towards the exit. This is what is found in the case of the stars. Each star has a motion of its own, and when these motions are considered in hundreds, a general movement from one point in the sky and a general movement towards a point on the opposite side of the celestial sphere is observed. The apex of the sun's way is the part of the sky in which the stars appear to be spreading out, owing to the motion of our system towards them, and the anti-apex marks the opposite part of the sky. If the stars were fixed, like trees in an avenue, the opening out would be similar to that observed in front when walking down the avenue, and the closing up would be analogous to the view behind. The problem would then be a very

simple one, whereas the reality of stellar motions makes it very difficult. Account must be taken of the movement of the solar system before the actual proper motion of a particular star can be stated.

Many of the stars undergo changes of brightness; they are "variable stars." Some fluctuate very considerably in brilliancy; others are not so conspicuously changeable; some rise and fall in light-giving power in the course of a few days; others slowly increase and as slowly decrease in splendour, taking several months to do so. In addition to the stars which periodically brighten and dim in this way, there are what are known to astronomers as "New Stars," or "Novæ," which appear in parts of the sky where no bright stars were previously seen. When Galileo turned his telescope towards the sky, he saw hundreds of stars previously unknown to man, and in our day increased optical powers and celestial photography are continually revealing new worlds. Such, however, are not known as "new stars." The term is reserved for those which blaze out suddenly and then slowly fade away to invisibility. About thirty temporary stars of this character have been recorded in historic time. The first of which anything like a circumstantial account was written appeared in 1572 in the constellation of Cassiopeia. During a short part of its existence, this star was so bright that it could be seen in the daytime, and it took fifteen months to fade out of sight. Another new star of exceptional grandeur was seen in 1604. Coming to more recent times, we have the star which in 1866 was suddenly exalted from the ninth to the second magnitude, and, after occupying this position for about a month, went back into the obscurity from which it had been raised. This was the first new star to which spectroscopic analysis was applied. The increased light was found to be of the quality emitted by hydrogen.

In 1876 a new star appeared in the constellation Cygnus. It was of the third magnitude when at its brightest, and in fifteen months had sunk to the eleventh magnitude. The

remarkable fact about this star is that when it had sunk to its lowest degree, and was presumably at a lower temperature than at the time of greater brilliancy, it was indistinguishable from a small nebula, or a comet when far away from the sun.

A considerable amount of interest was taken in a new star observed in the constellation Auriga in 1892. The analysis of the light of this star showed that we were really viewing two or more bodies, or parts of the same body, moving with different velocities and in different directions with respect to the earth. The star, like the new star of 1876, eventually assumed the condition of a small nebula, its light being of precisely the same quality as that given by these cloud-like patches in the sky.

During the present century, two conspicuous new stars, each of which became brighter than a star of the first magnitude, have appeared—one in the constellation of Perseus in 1901 and the other in the constellation of Aquila in 1918. Both these objects went through much the same changes in descending to the nebula stage as were exhibited by the Novæ already described.

It is possible only to speculate on the cause of the appearance of new stars. Some astronomers believe that the increase of brightness is caused by an enormous outburst of luminous material from a faintly luminous crust, or the shooting forth of a great mass of luminous hydrogen in a similar manner to that observed in eruptions on the sun, but on a larger scale. The changes through which new stars commonly go, particularly as regards the character of the light emitted, cannot be satisfactorily explained on this theory. A more reasonable view, put forward by Sir Norman Lockyer, is that new stars are caused by the clash of two swarms of meteorites in space, or by a dark globe penetrating into a mass of cosmic dust of this nature. When the collision occurs, a large amount of heat is developed, and the luminosity is increased so long as the cosmic material is in contact. After the collision the

prime cause of the production of luminous gases is removed, and the cosmic mass slowly returns to its normal state.

The most celebrated star which waxes and wanes in brightness in a period of several months is in the constellation Cetus, and is known as Mira Ceti—the wonderful star of Cetus. It is a typical "variable of long period." At the time of maximum brightness Mira is usually of the second or third magnitude, and sometimes rivals a star of the first magnitude. It then fades gradually away, and in rather more than a couple of months can only just be seen in a three-inch telescope. For nearly eight months the star remains in this unimportant state, when suddenly an increase of brilliancy sets in, and in about a month the star is again in the zenith of its power, clearly visible to the unaided eye. The interval between one maximum and the next is about 332 days.

A variable star of quite a different type is Beta Persei. The ancients were so much struck by the extraordinary behaviour of this object that they named it Algol—the Demon Star. For two and a half days Algol is of the second magnitude, and shines steadily like an ordinary star. Suddenly, however, it begins to dim, and in about four and a half hours it sinks nearly two magnitudes. But in less than half an hour Algol commences to brighten again, and in about four hours it has regained its normal magnitude. These changes are run through in 2 days, 20 hours, 48 minutes, 51 seconds.

In 1783, John Goodricke, of York, suggested that the apparent changes of Algol's light were caused by a dark body revolving round the star, coming between it and us once in a revolution and so causing it to be partially eclipsed. This theory has been established by spectroscopic observations of the star's back-and-forth movements. Algol has been proved to approach and recede from the earth in a period the same as that of its variation in light. It swings away from us and blinks, then rushes towards us, only to run away and blink again. These oscillations

are caused by Algol's dark companion. The dark star and the bright one are connected by gravitational attraction, as if by a long rod, and both move round the point on which the rod could be balanced; hence, when one is moving towards the earth, the other is being swung back. The

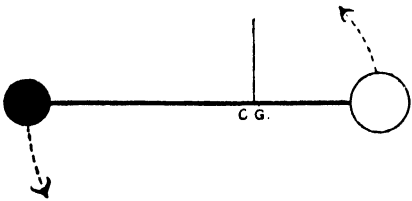


FIG. 48.—Movements of two bodies around their common centre of gravity.

spectroscope shows that Algol is receding from us when the dark body is coming forward to eclipse it. After the eclipse has occurred the dark star is being whirled away from the earth and Algol is approaching. To prevent misconception, it should be remarked that the fluctuations of brightness are not due in the slightest to Algol alternately approaching and receding from the earth. The bright star itself is of the second magnitude, both when it is moving towards us and when it is receding from us.

The movements of stars towards or away from the earth are determined by the spectroscope, the principle of the method being the same as that described in Chapter IV for the measurement of the motion of solar vapours. It might be supposed that the criterion of a star's direction of motion is change of brightness; but this is not so. If the nearest star were to approach the earth at the rate of one hundred miles a second, its brightness would not be increased by one-fortieth part in a century, and a motion of recession would only cause the same amount of diminution in this time.

We have said that the lines in a spectrum, like the notes of a piano, have a fixed pitch, which is altered, however, by relative motion backwards and forwards. The distance between us and a luminous body is immaterial, so long as it remains constant. But if the distance is diminishing all the spectrum lines are increased in pitch—are shifted towards the violet end of the spectrum, and if it is increasing a lowering of pitch is the result—the lines are shifted towards the red end of the spectrum. Suppose a piano were being hurried towards us on an express engine with the middle C note sounding. If we had a C tuning-fork of standard pitch, any change could be at once detected by sounding it and comparing the note with that received from the moving piano.

In a similar way, any change of pitch in spectrum lines can be found by merely observing or photographing the spectrum. It is necessary, however, to have a spectrum of standard pitch to compare with. This is easily obtained. Hydrogen, for example, shows a set of lines in particular positions when it is made luminous by electric action in the laboratory. The lines can be considered analogous to the C's of a piano. When we compare this set with those given by the light of some stars, perfect agreement of pitch is often found. On the other hand, the hydrogen lines of certain stars do not coincide with those of terrestrial hydrogen, but appear shifted towards the violet end of the standard spectrum. The obvious conclusion is that the star is moving towards the earth, and by measuring the amount of displacement, the velocity of motion can be calculated. When such a star is moving away from the earth, its hydrogen lines are displaced to the red sides of the lines in the comparison spectrum.

In 1868, Sir William Huggins used this principle for the determination of the motions of a few stars "in the line of sight," but photography has now almost entirely taken the place of visual observations of this kind. The spectrum of the star the motion of which is under determination is

photographed side by side with the spectrum of hydrogen, iron, or other convenient element. The displacement of each line in the star spectrum, with respect to the same lines in the terrestrial spectrum, is then measured, and the mean or average displacement found from the sum of the measures. The motions in the line of sight of many stars have thus been determined with a probable error of about a mile a second. Aldebaran is found to be running away from the solar system with a velocity of about thirty miles a second, while Altair is approaching us at the rate of about twenty miles a second.

In 1889, Prof. E. C. Pickering found that one of the lines in the spectrum of Mizar, the middle star in the tail of the Great Bear, was doubled at periodic intervals of 52 days. It was therefore concluded that the star consists of two very close together, and having the same kind of spectrum. If the pair of stars faced the earth and were in relative rest, a simple spectrum would be observed at all times, for one set of lines would overlap the other. But the periodic doubling of the lines testifies clearly to relative motion. When one of the pair is moving towards us, the other is being swung away from us. The approaching body has its spectrum lines displaced towards the violet end of the spectrum, while the lines of the receding one are displaced in the opposite direction. A separation of the lines is therefore seen. When, however, the bodies are moving across the line of sight, no such displacement occurs. Twice, then, in a revolution are the lines at their greatest distance apart, and twice do they overlap one another. Examination of a series of photographs of the spectrum of Mizar leads to the conclusion that the period of revolution of the pair of stars round the common centre of gravity is 20·6 days.

There are two stars very near to Mizar, one of which (named Alcor) can be distinguished by the unaided eye. Each of these has been proved to be a spectroscopic binary like Mizar, and there is also evidence to show that these

three pairs are physically connected. We are thus presented with the interesting spectacle of six stars rotating in pairs round their common centre of gravity, each pair possessing, in addition, an independent rotation of its own.

Beta Aurigæ is another star in which the lines are periodically doubled, but in this case the interval is only two days, indicating a period of revolution of four days. Each star has a velocity of about seventy miles a second, and the distance between them is seven and a half million miles.

In the star Capella, or Alpha Aurigæ, certain lines in the spectrum shift their positions periodically with reference to other lines. This is because the star really consists of two bodies of different spectral types revolving round their common centre of gravity. Using an accessory instrument, called an interferometer, on the 100-inch telescope of the Mount Wilson Observatory in 1919, the two stars which combine to make the composite spectrum of Capella were distinctly separated, and the conclusion arrived at from spectroscopic evidence was thus confirmed.

Alpha Virginis (also known as Spica) is a good example of another class of spectroscopic binaries in which the companion is a dark star, or at least not bright enough to indicate its presence by means of lines in the composite spectrum of the pair. It was the first of its class to be discovered; and the lines in this case, instead of being doubled, are displaced alternately towards the red and the violet, since only one set is visible. This system therefore is very similar to Algol; but its light does not vary, since the plane in which the companion star revolves does not lie near enough to the line of sight, and there is therefore no eclipse as seen from the earth.

Polaris has also been suspected of belonging to this class. The lines in its spectrum are displaced in a similar manner in a period of about four days. More recently, however, it has been shown to be another type of variable, so that these displacements may not arise from the same cause as

those in Spica, and it is possible that Polaris is not a true spectroscopic binary.

The discovery of spectroscopic binaries is a wonderful achievement, and doubtless the number of stars of this class will be added to in the near future.

There is a considerable number of stars like Algol which are periodically eclipsed in a similar way by a dark companion, and all are grouped together under the name of "Algol variables" or "eclipsing variables." It sometimes happens, however, that the companion star is not dark, though it may be faint compared with the primary. In such a case the light variations present a very different appearance. When the stars are side by side, as seen from the earth, we get the full benefit of the light from each star. Their mutual revolution, however, soon causes the fainter star to be partially eclipsed by the brighter, so that the total light received suffers a slight diminution. The maximum brightness is soon regained as the stars are separated by their relative motions, and it is then the brighter star's turn to be eclipsed as its companion swings round in front. This time there is a more decided decrease in the brightness, to be followed once again by a rise until the original conditions are regained, when the whole cycle is repeated. Beta Lyræ is a typical star of this type, and there are a few others, but they are not numerous and can only be regarded as special cases of Algol variables. Algol itself is suspected of having a "secondary minimum," which would indicate that its companion is not really quite dark.

Another very important class of variable stars, which includes most of those whose periods are comparatively short, is represented by Delta Cephei. This star was the first variable of its kind to be discovered, and is still a typical example of the class, to which the name of "Cepheids" or "Cepheid Variables" has consequently been given. The time taken to pass through one complete cycle of variations ranges in stars of the Cepheid type

from a few hours up to seven or eight days; and the manner in which the light varies is very different from that displayed by Algol. First there is a very rapid increase of brightness, often extending over several magnitudes; and when the maximum brightness is reached this is immediately followed by a comparatively slow decline in lustre—usually accompanied by one or more pauses in the descent—until the original magnitude is reached. The star then at once commences its upward climb to the maximum brilliancy and the whole process is repeated.

The origin of these fluctuations of the Cepheid variables will not admit of so simple an explanation as was the case with Algol; and although many theories have been put forward to account for them, none is entirely satisfactory in its details. Observations with a spectroscope show that the velocity in the line of sight is variable. When a Cepheid is waxing in brightness it appears to be rushing towards us, and when it is waning it recedes. Such a state of affairs at first sight would seem to imply the existence of a companion round which the star we see is revolving (as in the case of Algol), but there are numerous difficulties in the way of accepting this hypothesis, and probably the most satisfactory explanation so far propounded is the "pulsation" theory. This assumes that Cepheids are isolated stars; at least that the cause of their variability is inherent in the stars themselves. It is supposed that at an earlier stage of their career some kind of disturbance has started them in a state of vibration—in the sense of an alternate expansion and contraction. This vibration, or pulsation, may be compared, for the sake of illustration, with the beating of an animal's heart, which alternately contracts as it forces the blood through the arteries and then dilates in order to receive a fresh supply. A pulsation or "beating" of this kind would cause a star to brighten and fade in the manner required, since an expansion would be accompanied by an outflow of hotter material from the interior of the star all over its surface, which would

gradually cool down until replaced by a fresh outflow. This theory is strengthened by spectroscopic evidence which gives an unmistakable indication of higher temperatures with increasing brightness of the star, and vice versa.

It is easily seen also that in a case such as we have pictured the *surface* nearer to us would alternately approach

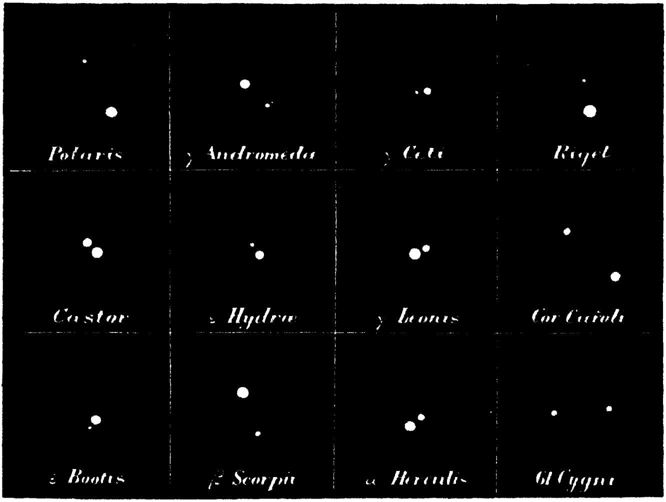


FIG. 49.—A few double stars.

and recede from us (although the star as a whole might be unmoved), and the apparent variations in " line of sight " motion already referred to would be explained.

To the various classes of variable stars already mentioned must be added a further group containing stars the variations of which do not appear to follow any definite law. Their light may remain constant for a time, but at very irregular intervals they rise and decline in brightness by

an amount which is not always the same. They are termed irregular variables, and most of them are rather red stars—such as Alpha Orionis and Alpha Herculis.

In addition to stars which have been proved to be under the influence of invisible companions, or to be too close together to be seen separately by direct observation, there are many stars which are seen to be double when observed with a telescope. Sir William Herschel was the discoverer of these revolving systems. He measured the distances between a number of stars which appeared close together when telescopically observed, and also the direction of the line connecting them. Repeating the measures after a time, he found that the separating distances and the direction of the connecting lines of pairs of stars had altered. Further observations proved beyond doubt that the component stars were slowly moving round their common centre of gravity, and at the present time hundreds of pairs of these distant suns have been observed to change their position and directions in a similar manner. In addition, several thousand pairs of stars have been recorded, though their motion relative to one another has not yet been detected.

When Herschel took up the observation of double stars, he did so with the idea of determinating stellar parallax by the differential method afterwards successfully used by Bessel. At that time double stars were considered to represent two objects which happened to lie in nearly the same line of sight, and systems of revolving suns were unrecognized. A few of the stars which appear to be double may be of this kind, that is, they are not really companions having a stately waltz in space, but only "optical" doubles; but these must be exceptional, as the probability of two stars being in nearly the same line as seen from the earth is very remote. The orbits of about fifty "physical" doubles or binaries have been calculated, and the time of revolution is found to vary from about five years to as much as a thousand years.

Though only comparatively few double stars have been

observed to complete a revolution or move in curvilinear paths round a point between them, more than ten thousand double stars are known and have had their distances and directions determined. As time goes on these measures will be compared with others to see if any changes have occurred during the interval.

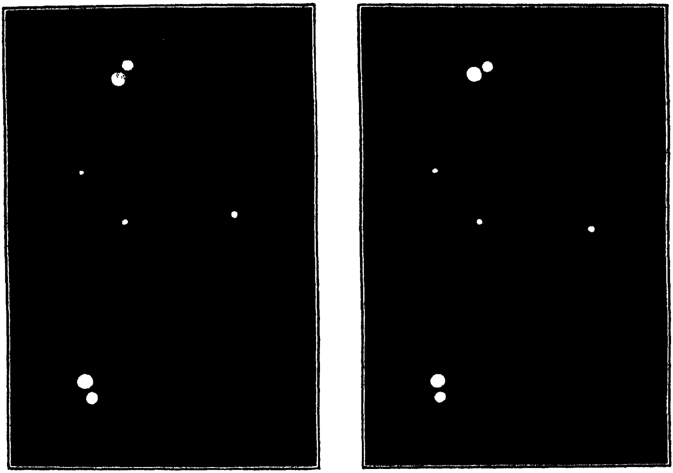


FIG. 50.—Views of ε Lyræ (the Double-double) and neighbouring stars at different dates.

Sirius has a peculiar history. Observations of its position indicated that it did not merely move in a straight line, but travelled in a small curved path, and in 1862 the minute but ponderous body which hampered its movements was discovered by Alvan G. Clark. The period of revolution of the Sirian system is fifty-two years. Procyon is a similar star the small or dark companion of which was discovered in 1896; its period is forty years.

Castor, one of the Heavenly Twins, is a good example of a binary star. To the naked eye it appears to be a single

star, but when viewed telescopically it is seen to be made up of two—one a magnitude brighter than the other—and each star of this pair has been proved to be a spectroscopic binary. The period of revolution of the pair is about one thousand years. Alpha Centauri, the star nearest to our system, is also a double, the period of revolution being about eighty years, and the mean distance being about twenty-three times greater than the distance of the earth from the sun. The star Epsilon (ε) Lyræ is very interesting. An observer gifted with acute sight can see that this object consists of two, without the aid of a telescope. By means of an opera-glass the duplicity is at once made out, and if a telescope of moderate dimensions is employed, each of the pair is seen to be a double, thus making the system a quadruple one. On this account the star is known as "the double-double." Each pair is revolving round the common centre of gravity, and at the same time the individuals of the pair are in motion round one another.

The components of a large number of double stars usually differ in colour when they differ in brightness. Beta Cygni is a beautiful example of this. When viewed in a small telescope, the star is seen to consist of two, one of the third, the other of the fifth magnitude. The brighter star has a golden-yellow colour, while the fainter companion is blue. Gamma (γ) Andromedæ is another but more difficult example of the same kind. Its components are respectively of the third and fifth magnitudes, the larger being yellow and the smaller sea-green.

The phrase "Nature finds gladness in a thousand tints," may indeed be applied to celestial as well as to terrestrial objects. We have stars of a bluish-white colour like Capella; of a bluish-green like Sirius; red, like Aldebaran; and yellowish-red, like Arcturus, and between one and the other there are shades innumerable. Like the flowers of the earth, the flowers of the sky are exquisite in their beauty and variety.

From double and multiple stars we pass to "clusters and

beds of worlds, and bee-like swarms of suns."* The Pleiades is a cluster in which six bright stars can be counted without telescopic aid. In the constellation of Cancer is a close assembly of stars—the Beehive—which appears like a spot

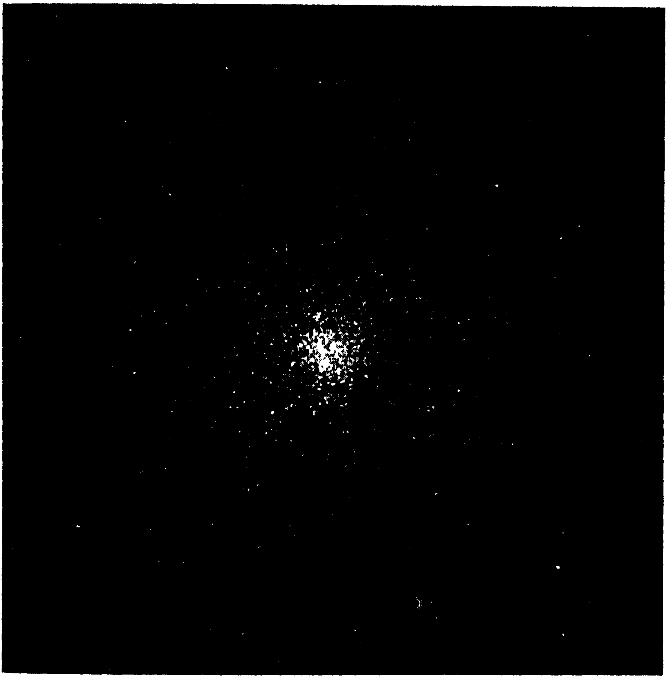


FIG. 51.—Photograph of the star cluster in Hercules. (M 13), taken by Dr. J. S. Plaskett, with the 72-inch reflector of the Dominion Astrophysical Observatory, Victoria, B.C., Canada.

of light when viewed with the unaided eye. An opera-glass shows that the spot consists of forty or fifty individual stars, and a telescope of moderate dimensions will show hundreds of stars packed in a small space. Another

well-known object of this kind is found in Perseus. It is a double cluster of stars, and can be fairly well seen with a

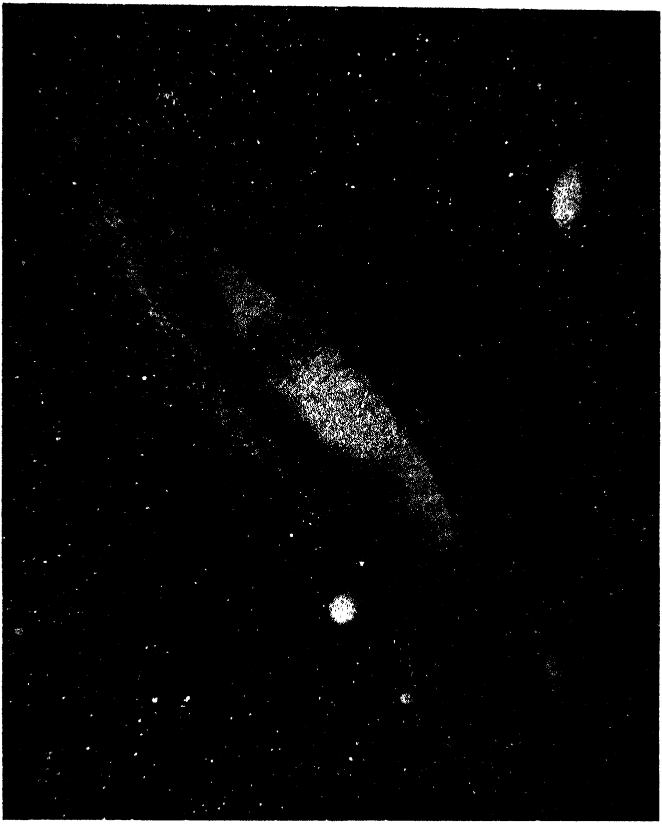


Fig. 52.—Photograph of the great Nebula in Andromeda, taken by Mr. G. W. Ritchey, with the 24-inch reflector of the Yerkes Observatory, University of Chicago.

good field-glass. More interesting than any of these objects is a globular cluster of stars in Hercules. In a small

telescope this cluster looks like a round patch of haze, but with a large instrument several thousand stars can be seen and counted.

Very similar in appearance to a star cluster seen with a telescope are the celestial objects known as "nebulæ"—clouds. They are faint patches and wisps of luminous haze set in the starry vault and playing a very important part in the universe. It must not be supposed that these celestial clouds are so transient as those of the earth. Changes doubtless happen, but from the time when nebulæ were first observed to now, no striking differences have been found.

Two nebulæ can be distinguished with the naked eye, one in Andromeda, the other round the middle star in the sword of Orion, Theta (θ) Orionis. A small telescope shows that this star is really composed of four, arranged in the form of a trapezium, and a large instrument adds two more. Surrounding the star will be seen an irregular area of mist—the Great Nebula of Orion. The Andromeda nebula is more easily seen with the naked eye than the Orion nebula though it does not cover such a large area of sky. In a moderate-sized telescope the nebula is seen to be a spindle-shaped mass of luminosity. Another interesting nebula occurs between Beta and Gamma Lyræ. It is ring-shaped and somewhat like the rings of smoke which many smokers can blow from their mouths. In addition to irregular, elliptical, and ring nebulæ there are many having a spiral or whirlpool form, and also others, known as planetary nebulæ, on account of their showing discs of almost uniform brightness. Nebulous stars have the appearance of points of light shining through a mist, and many bright points have wisps and lucid streams running out from them in curves and lines too diverse in character to admit of classification. Double nebulæ close together and far apart are also found in all sizes.

Many thousands of nebulæ are now known, and it is noteworthy that they are much more numerous in the

parts of the sky distant from the Milky Way than in or near it. Where stars are abundant, nebulæ, as a rule,

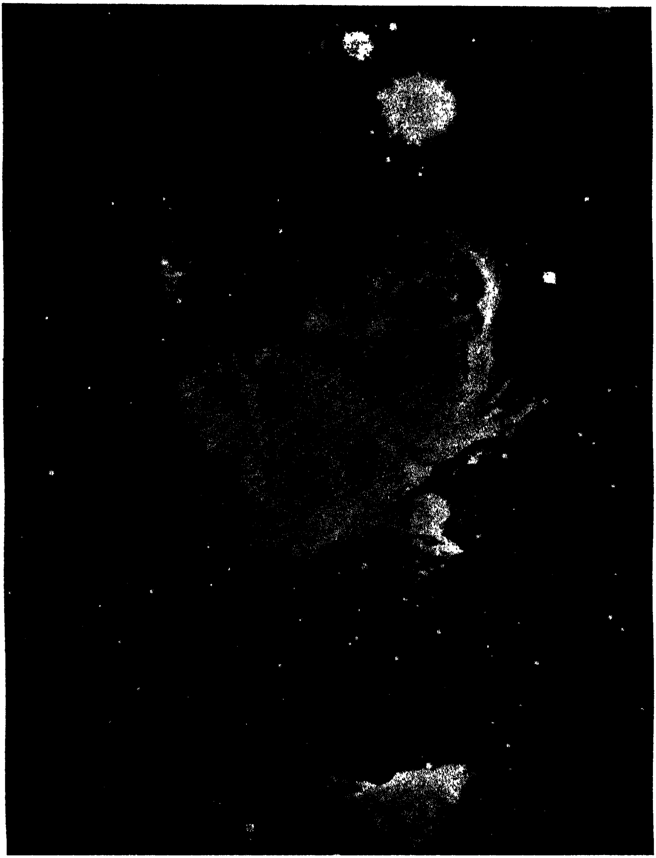


Fig. 53.—Photograph of the Great Nebula in Orion, taken at the Yerkes Observatory, University of Chicago.

are scarce, and in the regions in which nebulæ are found the heavens lose their richness as far as stars are concerned.

Like the stars, the nebulæ are found by spectroscopic observations to be in motion, and while one part of the Orion nebula, for example, is moving towards the earth, another part is receding from us. The radial velocities of nebulæ may be as much as forty miles a second, and in some cases there is definite evidence of rotation. It is difficult to think of nebulæ moving through space with these high speeds until it is remembered that the finest particle of matter can travel through a vacuum as easily as a solid mass.

Many clusters of stars, which look like nebulæ when viewed with a small telescope, are found to consist of individual stars if a larger instrument be employed. This led to the idea that all nebulæ are clusters of stars so far removed from our system as to be beyond the disintegrating or resolving power of our largest telescopes; once nebulæ were divided into two classes, one containing those which had been resolved or broken up by optical aid, the other containing objects which defied disintegration. This distinction, however, is not now maintained, for the spectroscope has shown that the light of gaseous nebulæ is not that which would be received from clusters of stars. The criterion as to whether an object is a true nebula is, therefore, the light badge revealed by the spectroscope, and not the telescopic appearance.

CHAPTER X

THE STELLAR UNIVERSE AND CELESTIAL EVOLUTION

STRETCHING across the sky at night is an irregular band of faint luminosity known as the Milky Way or Galaxy. Ancient philosophers speculated and disputed on the constitution of this belt of milky brightness, and it was not until the invention of the telescope that its true character was declared. "By the irrefragable evidence of our eyes," says Galileo, "we are freed from wordy disputes upon this subject, for the Galaxy is nothing else but a mass of innumerable stars planted together in clusters. Upon whatever part of it you direct the telescope, straightway a vast crowd of stars presents itself to view; many of them are tolerably large and extremely bright, but the number of smaller ones is quite beyond determination." The larger telescopes now employed bear out Galileo's observation and show that this celestial zone is "powdered with stars."

About ninety per cent of all the stars in the heavens lie in or near the Milky Way. As we recede from it in the celestial vault, the stars become less numerous and are fewest when we are at the poles of the galactic circle. On the assumption that the stars are of approximately the same size and intrinsic luminosity but at different distances from the earth, Sir William Herschel used his telescope as a "sounding-line" to fathom the depth of the stratum of stars in the Milky Way. His observations led him to conclude that our universe extends farther in the direction of the Galaxy than elsewhere. The stars

there appear closely packed and of every grade of brilliancy, because they lie one after another in nearly the same direction for a greater distance than in any other part of the sky.

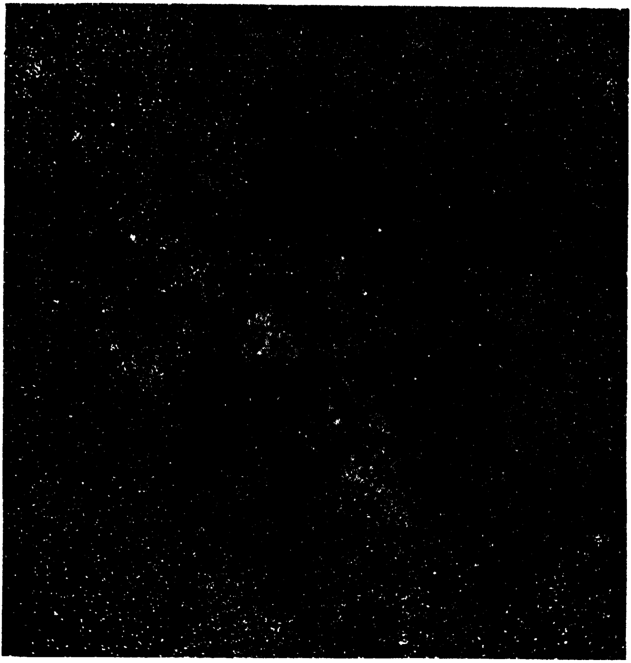


FIG. 54.—Photograph of a part of the Milky Way, taken by Prof. E. E. Barhard, at the Yerkes Observatory, University of Chicago.

Herschel, therefore, supposed the solar system to be situated not far from the centre of a system of stars, most extended in the direction of the Milky Way and least extended near the galactic poles. This was regarded as our particular universe, and beyond it other universes

were supposed to exist. Though Herschel's conclusions were little more than conjectures, the general views now

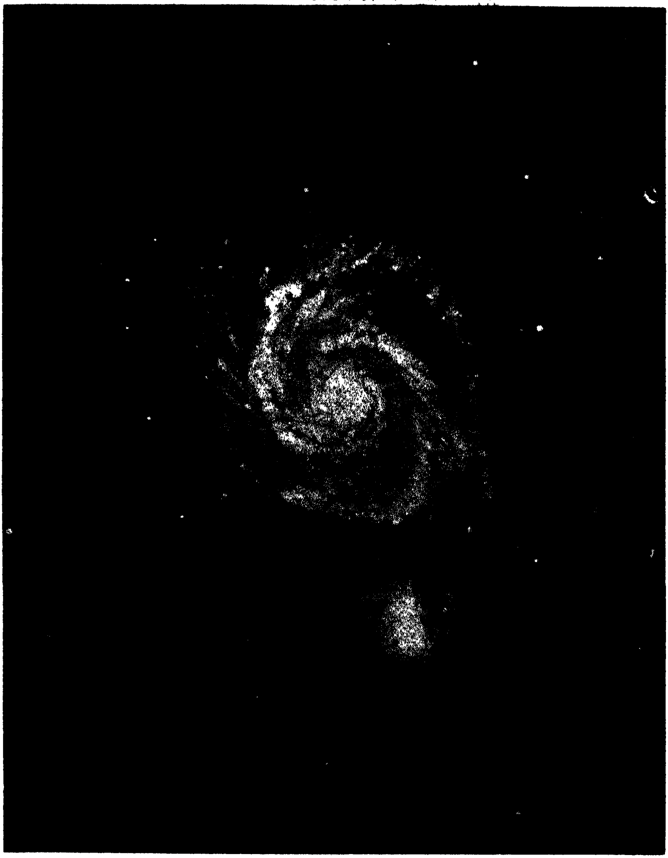


FIG. 55.—Photograph of the great Spiral Nebula in Canes Venatici, taken with the 60-inch reflector of the Mount Wilson Observatory.

held as to the shape of our universe do not differ very much from his. The Milky Way itself is believed to

represent far distant stars distributed irregularly around the circumference of a disc-shaped universe, and between these stars and us are clouds of non-luminous cosmic material which here and there blot out some of the starlight and are seen as dark patches on the sky.

A somewhat attractive hypothesis regarding the structure of the universe, which has recently given rise to considerable discussion, is that the spiral nebulæ are separate universes, entirely distinct from our particular system—which is formed as suggested by Herschel and called the "Galactic Universe." These nebulæ are regarded as comparable in size and structure with the Galactic system, though of course at enormously great distances from it. An approximate idea has been gained of the distances of spiral nebulæ from the appearance of "new stars" which are occasionally seen in them. These objects show all the peculiarities which are to be found in the new stars of our own system, and are, therefore, probably very similar in character. Thus, on the assumption that the actual brightness of these stars wherever they occur is on the whole always of the same order, the distance of a spiral nebula may be estimated from a knowledge of the apparent brightness of the new stars which occur in it. Considerations of this nature are found to suggest an average distance for spiral nebulæ of about 5,000,000 "light-years," i.e. light, travelling at the rate of 186,000 miles a second would require 5,000,000 years to complete the journey from a spiral to the earth. At such a distance a stellar system, even of dimensions so inconceivably great as those of our own system, would be reduced to the appearance of a mere patch of misty light, visible only with telescopic aid.

This hypothesis, although attractive in the grandeur of its conceptions, is, however, not fully supported by recent evidence. Dr. H. Shapley, of Mount Wilson Observatory, who has paid great attention to this particular subject, is of the opinion that the spiral nebulæ are comparatively

small in size and are situated within the confines of our galactic universe rather than at the enormous distances suggested above. "Island universes," as distinguished from our stellar system, may, and probably do, exist; but they do not come within the range of our observation. The galactic universe on this theory is about 300,000 light-years in diameter, and includes all objects visible in the most powerful telescopes. It can scarcely be said, however, that anything very definite is known concerning the form of the sidereal universe even at the present time.

Much is known, however, of the constitutions of objects which make up this universe. To be able to analyse objects, the nearest of which is about 250,000 times farther from the earth than is our sun, fills every one's mind with admiration. Let us trace briefly the history of this marvellous achievement.

In 1814, Fraunhofer, the perfecter of the spectroscope, and the observer of dark lines in the spectrum of sunlight, placed a large prism over the object-glass of a telescope and turned the compound instrument towards Sirius. The light from this brilliant gem of the sky fell upon the prism, traversed the prism, and was separated into its constituent parts, and then passed in this dispersed condition down to the eye of the curious optician. "I have seen," said Fraunhofer, "without any illusion, three dark lines in the spectrum of the light of Sirius which, apparently, have no resemblance with those of the sun's light. One of them is in the green and two in the blue space. Lines are also seen in the spectrum of other fixed stars of the first magnitude; but these stars appear to be different from one another in relation to these lines."

Little was added to these facts for half a century, when Father Secchi of Rome, and Sir William Huggins, took up the inquiry. The meaning of the dark lines in the solar spectrum was then understood, and astronomers were beginning to recognize the importance of the spectroscope

as a weapon of research. The analysis of the light of "the distant suns" followed as a necessary consequence. The spectrum of Sirius was found to consist of a few dark lines upon a rainbow-tinted ribbon of light. One after another, substances were vaporized and rendered luminous in order to find those which possessed bright lines coincident in position with dark lines in the star-spectrum. Hydrogen

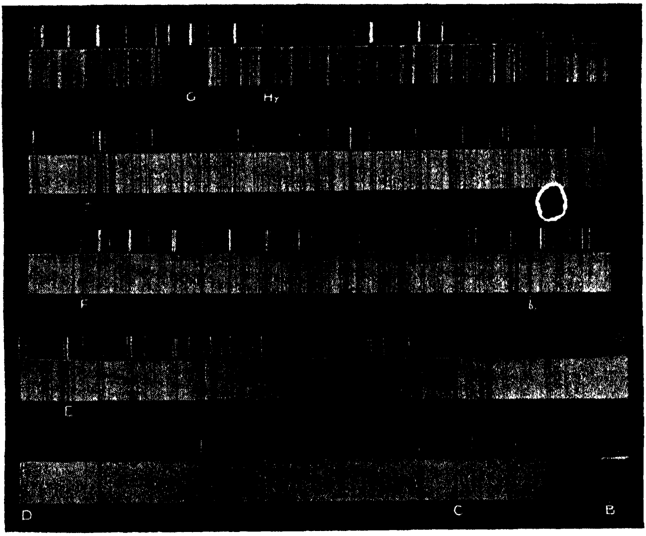


Fig. 56.—Photographs of portions of the spectrum of Arcturus compared with that of iron, taken at the Mount Wilson Observatory. Notice the coincidences of the bright lines (iron) with dark lines of the star's spectrum.

was thus shown to be the chief constituent of the Sirian atmosphere, and other elements identified were magnesium, sodium, iron, and calcium.

The radiations which reach us from the stars are unintelligible without the spectroscope. Each substance comes to report its existence in its own language, and a

babel results from their simultaneous speech. But the spectroscope singles out from this confusion of tongues the different languages, and bids each clamouring voice take up its proper position. The interpreters are then called from the laboratory. The hydrogen language of this earth proves to be that of the skies, and the many inflexions in the language of terrestrial iron are found to agree with those in which the light-ambassadors from the orbs of space have been speaking to us for thousands of years. Many other languages of light have been identified, but there are still some for which no interpreter has yet been found.

Father Secchi was the first to attempt to classify the stars according to their spectra. Four main types of stellar spectra were recognized by him. White stars, like Sirius and Vega, usually possess spectra in which a few broad, dark lines due to hydrogen are conspicuous. Yellow stars, like Arcturus, have spectra in which a large number of fine lines, chiefly due to iron, are visible. If the sun were taken away into space until it appeared of the same brightness as Arcturus, the spectra of the two would be found to be almost exactly alike. Red stars, like Betelgeuse (Alpha Orionis), show spectra entirely different from the first and second types. Instead of lines, dark bands are seen, each of which fades away in the direction of the red end of the spectrum. The fourth type established by Secchi contains a few faint stars of a deep red colour, having banded spectra like the third type, but the bands fading away in the direction of the violet end of the spectrum.

This classification roughly distinguishes the chief kinds of spectra, and is the one generally used at the present time. It is analogous to the division of the animal kingdom by early naturalists, into vertebrate or back-boned animals; articulated or jointed animals, like lobsters; molluscs, like snails, and oysters; and rayed animals, like starfish. Each of these divisions contains a number of different classes, which are again divided into groups or orders, and

there is no saying where one order ends and the next commences. In the same way, there is no sharp distinction

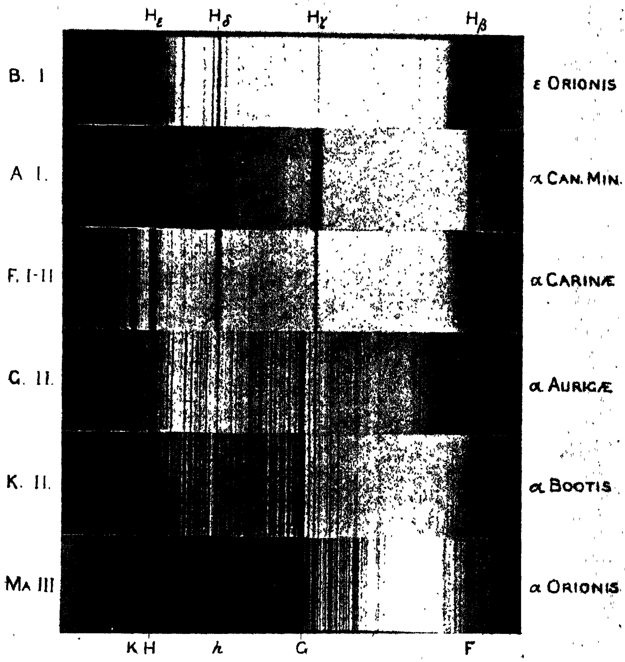


FIG. 57.—Photograph of typical spectra of stars, taken at Harvard College Observatory.

between the different types of star spectra ; and though Secchi's arrangement holds good in the main, the spectroscopic discoveries of recent years make a more detailed classification essential.

The system most generally known and adopted at the present time is that devised at the Harvard College Observatory. In this classification stellar spectra are divided into eight main groups designated by the letters O, B, A, F, G, K, M, and N respectively. In an earlier attempt the number of divisions was much larger, thus necessitating the use of more letters. Later research, however, showed the advisability of omitting some of these and rearranging the remainder, so that the seemingly arbitrary selection of letters mentioned above was the final result.

Spectra of type O are characterized by the presence of bright lines instead of the usual dark lines which are typical of the majority of stellar spectra. In Class B these bright lines have disappeared, and the typical features are a few fine dark lines only. These are due chiefly to hydrogen and helium, together with fainter lines of oxygen, carbon, and some other substances. In spectra of Class A very little is to be seen except the hydrogen lines, which are very strong and broad. Sirius and Vega belong to this class, which corresponds to Secchi's Group I. Below Class A many dark lines due to various metals begin to develop in stellar spectra. These are quite numerous in Class F, although the strong hydrogen lines (together with two lines of calcium) still form the most conspicuous features. Procyon may be regarded as representative of this group. Classes G and K correspond practically to Secchi's Group II. The hydrogen lines are no longer so conspicuous, and a very large number of fine metallic lines have made their appearance. The two remaining classes (M and N) are identical with Secchi's Groups III and IV respectively.

These eight main divisions are not sufficient to include the many smaller variations which are found to exist in stellar spectra. In order, therefore, to make the classification more detailed, the interval between each main group and the next is subdivided into tenths, each sub-

division being represented by a small number affixed to the type letters. For example, a spectrum which shows the strong hydrogen lines typical of Class A, but possesses in addition a few of the more conspicuous metallic lines (which are well developed in Class F) might be of the type A_5F—which indicates a group half way (five-tenths) between A and F. This is always abbreviated to A_5, which can lead to no ambiguity, and is more convenient. Similarly a spectrum described as G_2 would be one intermediate between G and K, but more nearly resembling the G type (two-tenths of the way from G to K). In this way the great majority of stellar spectra can be classified with considerable precision.

The spectra of most of the stars, like that of the sun, show dark lines due to the absorption of light in their atmospheres. Such and so was the knowledge, when, in 1864, Sir William Huggins turned his telescope, armed with a spectroscope, to a nebula in the constellation Draco and observed, to his astonishment, a solitary bright line instead of a multitude of dark lines. Further scrutiny showed two more bright lines, fainter than the one into which all the light of the nebula seemed to be concentrated. Never was there a more significant observation. Nebulæ had been considered to be stars clustered together and sunk so deep in space as to lose their individuality even when observed with the most powerful telescopes, but the spectroscope disposed of this idea by showing that the light of true nebulæ differed in quality from the light of any stars then known.

To the three bright lines thus seen in nebular spectra, later observers have added five more. Three of these lines are certainly due to hydrogen, and one is the line usually seen in the spectra of solar prominences, and due to the element helium. Spectroscopists are not agreed as to the substances which give rise to the remaining lines; even the origin of the bright line which is the trade-mark of green nebulæ is undecided. It has been named *Nebulium.*

and Prof. J. W. Nicholson has proved that several other "unknown" lines in the spectra of nebulæ are due to the same substance, although its true nature is not known. The spectra of white nebulæ like the nebula of Andromeda and spiral nebulæ do not show bright lines, but a continuous band of colour with dark lines superposed.

In recent years our knowledge of the spectra of nebulæ and stars has been very considerably extended by photography, many new lines having been recorded by its aid. A photographic plate replaces the eye of the observer and receives the spectrum upon its sensitive film. By means of specially prepared plates, the lines from the yellow to the violet in the visual spectrum can be photographed at the same time as lines in the invisible part of the spectrum beyond the violet. The colour is not photographed, but the lines can easily be recognized upon the picture, for each occupies its proper relative position. The same holds good in the invisible or photographic spectrum of a star, the relative positions of lines being always the same. We emphasize this point because students have a difficulty in understanding how it is possible to know one line from another in a photograph of a spectrum, since there is no colour guide. The double yellow line of sodium, and the green triplet of magnesium when once seen are recognized for ever after. When a specially prepared photographic plate, instead of the eye, receives the impressions from these lines, the negative obtained shows the sodium pair and the magnesium triplet as black lines. But though no colours are exhibited, the sodium pair will be at exactly the same distance from the magnesium triplet as was observed with the eye. Usually, when spectra are photographed, none of the lines in the green, yellow, and red parts of the spectrum leave their impressions upon the plate, but only lines in the blue and violet and those too high in the light-scale to be perceived by the human eye.

There is really no hard and fast distinction between a

star and a nebula; for some stars—if the word is not a misnomer—have a spectrum exactly like that of nebulæ, that is, a spectrum of bright lines. These are the stars of type O in the Harvard classification, and are also known as "Wolf-Rayet" stars from the names of their discoverers. In the light of these facts it cannot be held that nebulæ are entirely distinct from stars. There is certainly a considerable difference between a nebula and a star like the sun, but the difference is very probably only one of development.

The spectroscope shows that nebulæ merge into stars, and that star spectra of the different types pass by almost insensible gradations one into the other; hence it is as impossible to say, here one kind of spectrum begins, and there another kind ends, as it often is for the naturalist to draw the line of demarcation between different species of organisms. This is now generally recognized. Stars are believed to be evolved from nebulæ, and as they grow old, to change their quality of light, the spectroscope thus confirming the conclusion arrived at by Sir William Herschel from a study of the telescopic appearance of celestial objects. He found planetary nebulæ merging into nebulous stars, stars surrounded with a large amount of nebulosity, and others possessing but a small hazy mist or halo. Double nebulæ appeared to form double stars, and large masses of nebulosity to break up into star-clusters. In no one case could this development be traced, but Herschel's observations showed that the finished star and nebulæ are connected by such intermediate steps as to make it highly probable that every succeeding state of the nebulous matter is the result of the action of gravitation upon it while in the preceding one; and by such steps irregular nebulosities are brought up to the condition of planetary nebulæ, from which it passes to a nebulous star, and then to the completed product.

Though astronomers are of one mind as to the evolution of celestial species, they are not agreed as to the constitution of nebulæ, or as to the relative ages of stars. As glowing

hydrogen is present in nebular light, it would seem that nebulæ must be purely gaseous bodies. But this is not at all certain. Nebulæ may be composed partly of innu-

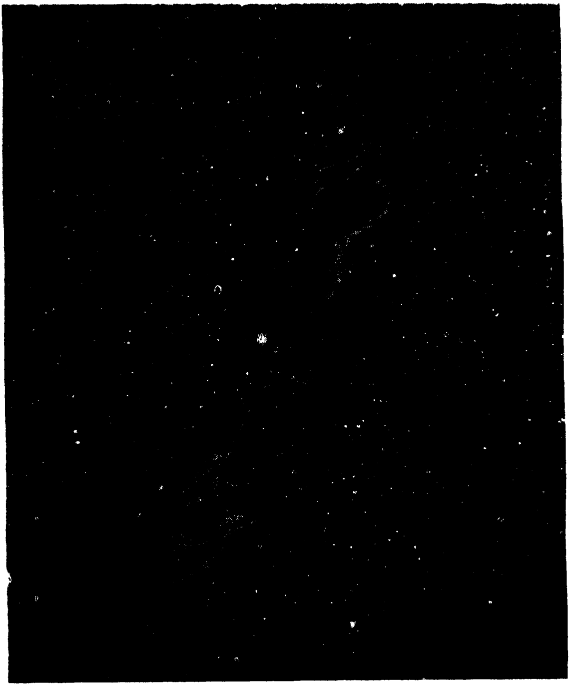


FIG. 58.—Irregular nebula in Cygnus, photographed by Mr. G. W. Ritchey at the Mount Wilson Observatory.

merable solid particles colliding and jostling one another, and thus provoking sufficient heat to drive some of their constituents into vapour and electric action to make it luminous. When a meteorite is heated, a quantity of hydrogen gas is usually driven off, which can be rendered

luminous by suitable means in the laboratory. It is reasonable, then, to conclude that a swarm of meteoritic particles in space, when rendered hot by friction against one another, would evolve gas which would be made luminous, and so be revealed by the spectroscope. The basic principle of Sir Norman Lockyer's "meteoritic hypothesis" is that a nebula consists, not of a mass of gas, but dark cosmic dust in motion like a swarm of gnats in the air. The swarm of dark particles gradually becomes surrounded with gases driven off by heat due to friction and rendered luminous by electrical action. Collisions and grazings increase as the swarm condenses; until finally all the particles have been driven into vapour. The vaporous globe cools; it sinks to the condition of our sun, of the earth, of the moon. And possibly, though here we have no evidence, bodies in the same stage as our satellite may eventually break up to form meteorites, which, by condensing into groups, would give a repetition of the phenomena.

Using this theory of celestial evolution as a groundwork, Sir Norman Lockyer built up a classification of the spectra of celestial bodies more comprehensive than any other. He divided the spectra into two distinct series of groups. The first of these corresponded with the evolution of a star from a cool swarm of meteorites to an extremely hot body in which all the solid particles have been vaporized. The second series represented the changes of a star in cooling and condensing into a cold solid body like the earth. Each of these series included eight or nine groups, and each group was named after some prominent star which it contained. Thus one group was named Rigelian (from the star Rigel, which was a typical example), another was named Sirian, another Arcturian, and so on. The "Alnitamian" group contained stars which had reached approximately the highest point in their evolution, and for a time were neither increasing nor decreasing in temperature. This group was therefore common to the

two series, and formed a connecting link which merged them into one continuous scheme.

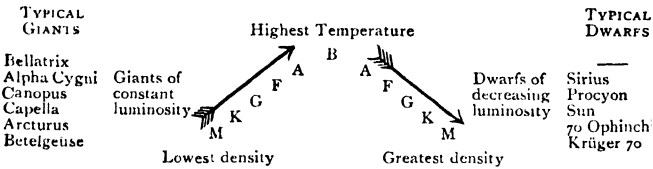
According to such a scheme of evolution it is evident that any particular temperature will be attained by a star twice during its life-history—once during its upward climb to the highest temperature and again while decreasing its temperature on the way to final extinction. Thus, for each group in the series of ascending temperatures there will be a corresponding group of approximately the same temperature in the descending series. Stars of the "Polarian" group, for example, are of nearly the same average temperature as "Procyonian" stars, although the former are becoming hotter and the latter are cooling. At first sight it would be natural to expect that spectra of these two types would be widely different from one another, since one represents stars in a very extended state consisting of meteorites which are only partially vaporized, with the interspaces occupied by very tenuous gases, while the other group represents stars in which the meteorites have all long since been vaporized, and are now condensed to relatively compact gaseous or even semi-liquid globes. This, however, is not the case, since the greatest factor controlling the general appearance of a star's spectrum is the actual temperature apart from any other physical conditions. Sir Norman Lockyer, however, recognized certain minor differences which he considered sufficient to differentiate the two main divisions of ascending and descending temperatures mentioned above.

Though there are differences of opinion as to the cause of these different kinds of spectra, to Sir Norman Lockyer belongs the credit of arranging star spectra in a continuous sequence from nebulæ up to stars of the highest temperature and down to bodies on the verge of extinction. Secchi's classification of spectra was entirely founded upon appearance. The Harvard system is based upon descending temperatures, all the stars being supposed to have cooled

from the condition of the O- and B-type stars. Lockyer based his arrangement upon the very reasonable view that there are stars increasing as well as decreasing in temperature, and this remains true, whether stars are believed to be evolved from cosmic dust or not.

Although the nomenclature used by Lockyer has not been generally adopted, the main idea underlying his classification has received considerable support from recent astronomical work. Prof. H. N. Russell has approached the subject from a different point of view. By bringing together all the available information with regard to stellar distances and masses, he has been able to compute the sizes, luminosities, and densities of a considerable number of stars. In this way he has shown that each group of spectra in the Harvard classification represents in reality two distinct types of stars. The first of these (which has received the name of "giants") are of great size and very high total luminosity, but of extremely low density. Although the masses of these stars are comparable with the average mass of stars in general, the matter contained in them is extended to fill enormous volumes, and hence the average density is reduced to an extremely low value (in some cases considerably less than that of air). The second group (called "dwarfs") are very much more condensed, and much smaller in size, being in a condition similar to that of our own sun. The distinction between giants and dwarfs is very well marked in the stars of "cooler" spectral types (G, K, and M), but above type F it is not nearly so pronounced, and in the B type (which correspond to Lockyer's "Alnitamian" group) the two are so merged together as to be practically indistinguishable. This evidently bears out the theory underlying Lockyer's classification, in which the stars of the ascending series correspond to Russell's "giants" and of the descending series to the "dwarfs." Although the details are not altogether in agreement, and the foundations are entirely different, yet the principle is the same in each case.

The life history of a star as it passes through the various spectral types in the giant stage to its highest temperature, and then back through the same types as a gradually cooling dwarf, may be shown graphically in the following diagram (which was given by Prof. A. Fowler in his Presidential Address to the Royal Astronomical Society in 1921):



A most important piece of evidence in favour of the existence of giant stars has recently been afforded by the striking achievement of Prof. A. A. Michelson, who has perfected an instrument whereby the apparent diameter of stars may actually be measured. Even the largest and nearest stars have apparent diameters so excessively small as to be beyond the reach of ordinary direct measurement with the most powerful telescope in existence; but with the help of his "interferometer" (specially adapted to the great 100-inch telescope of Mount Wilson), Prof. Michelson has been able to determine with considerable accuracy the diameters of several stars. The star Betelgeuse was thus proved to have a diameter of 215 million miles, or 250 times greater than the diameter of the sun, and Antares—another red star of the "giant" type—was similarly found to have a diameter of 400 million miles. These results agree remarkably well with the theoretical values predicted by Prof. A. S. Eddington and Prof. Russell, and thus afford independent evidence of considerable value in support of the theory of stellar evolution from attenuated cosmic matter—nebulæ—briefly outlined above.

Attempt to draw a patch of mist lying over a water surface in the evening or a thin bank of fog, showing not only the extent of the haziness but the light and shade of its parts, and you will obtain an idea of the difficulty of

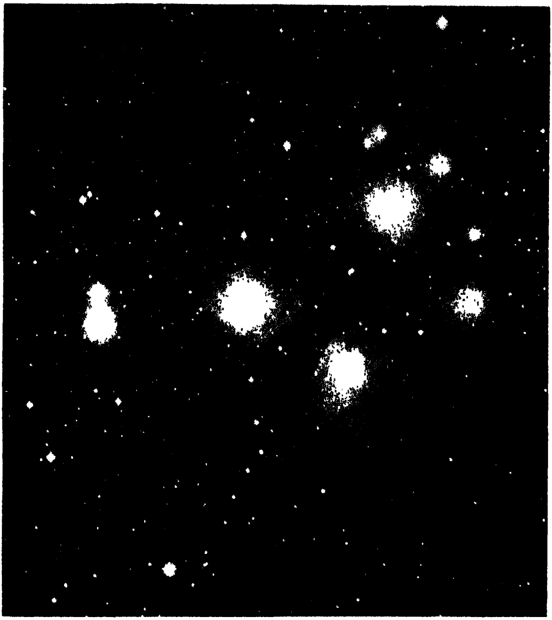


FIG. 59.—The Pleiades. Photographed by Dr. Isaac Roberts.

accurately delineating the structure of nebulæ. From 1659, when Huyghens published the first drawing of the Great Nebula of Orion, to 1880, when Dr. Draper took the first photograph of it, one observer after another had attempted to reproduce its ghost-like form, and the results were often so different that it is difficult to believe that the same object was represented. Dr. Draper's results showed

clearly that much was to be expected from photography as a nebula artist, and pictures obtained since by various celestial photographers have proved the art worthy of the trust which was put in it. Details and extensions of the nebula, previously unknown, have been revealed by photographs.

Unaccountable dark lines or rifts seen on drawings of the Great Nebula of Andromeda have been shown by photographs of the object to be divisions between rings of luminous matter, extending completely round it, like the rings round the planet Saturn. Similarly, photographs of the Pleiades cluster of stars have shown that the whole of the stars in the cluster are immersed in nebulosity, whereas not a trace of this cloudiness can be seen with an ordinary telescope.

If nebulæ are considered to be the starting point in the life history of worlds, it is possible to select from them examples in every stage of growth from formless mist to finished star. When we go into a forest and see the brave old oaks which have stood in their might and majesty for hundreds of years, side by side with the saplings and the plants just sprouting from acorns, we know at once that the different forms represent different stages of development. Reasoning in this manner, Herschel concluded that the various forms of celestial bodies are the result of different ages, and that every world has been fashioned out of the misty material we call nebulæ. The nebula in Orion appears to represent the condition of things when "the earth was without form and void; and darkness was upon the face of the deep." In the nebula of Andromeda we have a more symmetrical arrangement of matter. Round the bright nucleus are swirls of luminosity, which appear elliptical in form on account of their being inclined to the line in which we see them. The two small nebulæ near this "tumultuous cloud" have very probably been formed from it; they are worlds being called out of a void. A nebula such as that of Andromeda may therefore be older

than an irregular mass like that of Orion. The next stage of development is into a star cluster immersed in faint nebulosity, and then into clusters quite free from this "shining mist." Thus, on the somewhat insecure basis of appearance, attempts have been made at a classification of celestial species.

Kant and Swedenborg speculated upon the evolution of the members of our system, and Laplace developed the matter mathematically. It was assumed that the space included within the limits of the solar system was at one time filled with a whirling, luminous mass, similar in constitution to a nebula. This rotating ball of vapour gradually diminished in temperature, and, as it contracted by cooling, the rotation increased in rapidity until the centrifugal force became greater than the central attraction, and rings or zones of nebulosity were left behind. The condensation of these rings produced planetary masses, which, by going through similar stages to the parent mass, gave birth to satellites. The planet Saturn is surrounded by rings, which it was suggested, will probably break up into satellites in this manner.

According to this nebular theory, Neptune is the first born member of the solar system and Mercury is the youngest. The meteoritic hypothesis is really an extension of the nebular theory, for it has been shown that a condensing swarm of meteorites would behave like the condensing mass of gas upon which Laplace based his theory. The nebular theory begins with a ready-made gaseous nebula, whereas the meteoritic hypothesis begins at an anterior stage of obscure cosmic particles, from which the mass of gas is produced. A more recent hypothesis, which in some points resembles the meteoritic, is that of Profs. Chamberlin and Moulton (known as the "Planetisimal Hypothesis"). This was put forward to account for the origin and present configuration of the solar system in particular, since that presented peculiar difficulties in the way of an explanation by any of the existing

hypotheses, but it does not exclude the possibilities of other systems having been formed in totally different ways.

The authors of this hypothesis assume the sun to have existed before the formation of planets, in a condition

FIG. 60.—Spiral nebula in Andromeda, photographed at the Mount Wilson Observatory by Mr. G. W. Ritchey. The nebula is seen edgeways, and the photograph shows dark matter obscuring part of the bright centre.

comparable with its present state, and to have been approached comparatively closely by another star. Such an approach would cause very great tides on the sun, in a manner exactly analogous to the production of our tides by the moon, only on a much larger scale. The matter of the sun would tend to be heaped up at two points—one immediately facing the other star, and one at a diametrically opposite point on the sun. If the tide-producing

forces were large enough there would be considerable eruptions of matter from the sun in these two opposite directions. These ejections are supposed to have occurred spasmodically, and of course would be greatest at the time

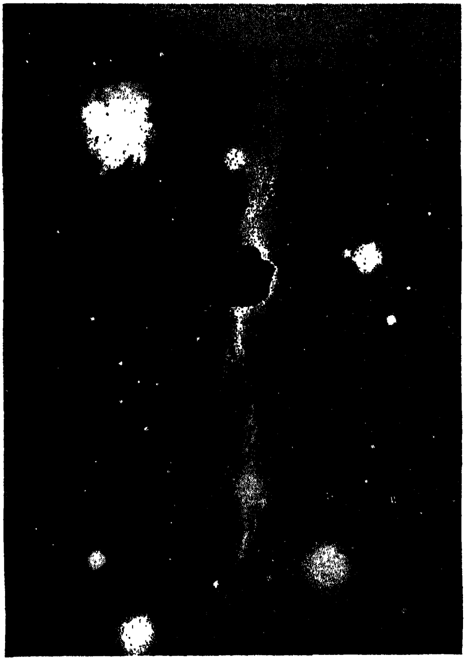


FIG. 61.—Photograph taken by Mr. Duncan with the 100-inch telescope of the Mount Wilson Observatory, showing nebularity south of ζ Orionis, and a dark, cosmic mass projected upon it.

of nearest approach. Owing to the original rotation and combined attraction of the two main bodies, the ejected matter would tend to lie on two spiral arms extending from opposite points of the sun, and containing occasional

condensations or " knots " representing the more violent eruptions. An origin is thus suggested for the numerous spiral nebulæ which are to be found in the sky, their variations in size and form being accounted for by variations in size and closeness of approach of the two parent stars.

After this stage had been passed this theory assumes the ejected solar material to have revolved round the sun as " planetesimals " in numerous orbits (thus differing from the meteoritic hypothesis, in which the motions of the meteorites are haphazard, like molecules of a gas). The larger condensations mentioned previously would gradually increase in size through the absorption of planetesimals by collision and gravitational attraction, while their orbits would tend to change from the original elongated form into a more nearly circular type. In this way the planets are supposed to have been formed, and the smaller condensations in their neighbourhood are taken as the origin of their satellites.

This is probably the most satisfactory theory at present suggested to account for the evolution of the solar system; but it is not necessarily universal and may not be the general, or even the most frequent method employed in the birth of worlds, although the large number of spiral nebulæ at present discovered seems to suggest for it a wide applicability. It is usual to accept the view of the conversion of nebulæ into stars and planets and to extend it to the innumerable worlds distributed through the realms of space, but it can scarcely be said that our knowledge of celestial evolution is of a very accurate character. By patient searchings, however, man will obtain a deeper knowledge of the mystery of creation, and the light of science will yet reveal much that is at present hidden as to the nature and meaning of the myriad systems which make up the stellar universe.

The stellar universe is bounded only by man's perception of it. Before Galileo it consisted of less than five thousand visible stars, but the telescope and

photographic plate have increased this number to about one thousand million. There are, in addition, thousands of dark stars and many vast masses of cosmic dust; so that all the millions of celestial objects which can be seen or photographed represent only a part of our universe, and in all probability the smaller part. Astronomy has, indeed, in recent years been concerned largely with dark stars and other cosmic matter which the human eye can never see or the photographic plate portray.

Many dark patches and rifts are found in the Milky Way and other regions of diffused nebulosity, and from their character, as well as their position, there seems little doubt that they are clouds of dark matter projected upon a luminous background. One sharply-defined marking of this kind occurs near the star Zeta in the Constellation of Orion, and it is known to be much nearer to us than the Milky Way itself, which lies towards the limits of our stellar universe. A perfectly starless region in the sky may thus be due not to the actual absence of stars in that part of the celestial sphere but to a cloud of invisible substance obscuring the light behind it.

In the structure of the universe conceived by Brahma, many precious things were purposely kept hidden in order that man should exert his intelligence in the effort to discover them. Some of these things are now being revealed, and they teach that there is much more in heaven and earth than was ever dreamt of in the philosophy bounded by what the senses can directly perceive. By knowledge thus secured the spirit of man may rise above a world of struggle and transient intention into an intellectual sphere where he will indeed be but a little lower than the angels.

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